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THE MEASUREMENT
— OF —

ELECTRIC CURRENTS.

ELECTRICAL MEASURING INSTRUMENTS,
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METERS FOR ELECTRICAL ENERGY,
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PREFACE.

The object of both of the valuable papers presented before the Institution of Civil Engineers included in this volume is to review the advances made of late years in the production of what may be termed commercial instruments for measuring commercial currents. In other words, the authors devote their attention to the instruments having more or less of practicability to recommend them for the work of recording station output and securing station income. More than one class of apparatus is necessarily embraced within such a survey, and the paper by Mr. Swinburne is laudably comprehensive, there being in it a description in some detail, or a broad generalization that covers its principle, of well nigh every instrument that the electrical engineer cares to know anything about.

The paper by Mr. Wordingham looks at the question of measurement more specifically from the standpoint of the consumer's installation, but even in this respect it is an admirable and useful supplement to Mr. Swinburne's treatise. The use of meters for consumers is still far from being universal in America, but the discussion of the subject in this little book should serve to convince current producers and current consumers that the stage has been reached at which meters are available upon whose scientific accuracy full dependence may be placed. The extension and prosperity of electric light and power enterprises today will be helped by the employment of meters; while the greater use of these instruments will in turn stimulate to the construction of newer types embodying in a higher degree than ever the qualities of simplicity, cheapness, trustworthiness and durability.

T. C. M.

ELECTRICAL MEASURING INSTRUMENTS.

As the electrical industry develops, the methods employed in all its branches depart more and more from those in use in scientific laboratories. The vast strides made during the last ten years in the commercial use of electrical energy, are marked by departures from the practice of the experimental physicist, and approach to that of the mechanical engineer. In short, electrical engineering is daily becoming an important branch of civil engineering; and this has brought about a complete change in the methods of measurement. There are now workshop, as opposed to laboratory, instruments. It must not for a moment be supposed, however, that they are therefore necessarily less accurate. If one or two voltmeters were made in the year to supply the wants of a few laboratories, they would be bad and expensive; but when such instruments are turned out by the thousand, it is possible to devote much time and trouble to the design, and to make instruments at a low price which are accurate in use; just as the modern, low-priced American watch can be made better than its hand-made predecessors. Accuracy and low price are not, however, the only important considerations. Commercial instruments must be easy to use—that is to say, they must be direct reading or nearly so; they must not demand temperature corrections or other calculations, and they must not be affected by local magnetic fields. These various instruments form the subject of this Paper. It is, however, unnecessary to discuss measurements that are the same in the workshop as in the laboratory, as descriptions, for instance, of methods of taking resistances with an ordinary Wheatstone bridge are given in every electrical text book. In such cases, it will therefore be advisable to describe only those methods or instruments which are specially needed in commercial work, such, for example, as the determination of very large conductivities or very high electrical resistances. The exact measurement of resistances has been very thoroughly developed by telegraph engineers, and full information on this subject can best be obtained from the various telegraph manuals.

VOLTMETERS AND AMPEREMETERS FOR CONTINUOUS CURRENTS.

These two classes of instruments may be best discussed together, because in very many cases they differ in the windings only—that is to say, nearly all continuous current voltmeters measure a small current which is proportional to the pressure on their terminals. There is one point of difference to which more attention is now being paid, and that is, that for use in central stations and in private installations, a voltmeter should be arranged to give clear and accurate readings through a small range. For instance, a station supplying at 100 volts does not require its voltmeters to read from 10 to 150 volts, but should be provided with instruments whose whole scale is devoted to readings between, say, 97 and 103 volts, if there are no feeders. The amperemeters, on the other hand, may be used for any currents up to their maximum. Stress is laid on these points because they are not generally realized either by instrument makers or purchasers. For years, designers have been devoting unlimited ingenuity to making instruments with equally divided scales. An equally divided scale is of no value, and, to secure approximately proportional readings, other important considerations in the design may have to be sacrificed. In addition to giving the readings required, all instruments should be direct-reading—that is to say, the index should point to the pressure or current, and there should be no turning of buttons on the top, or of reference to tables. Instruments whose indexes have to be brought to zero, such as the well-known Siemens dynamometer, have been of enormous value in the past, and have not yet been quite replaced in alternate current work; but though indirect reading instruments have still to be used, in many cases they should be avoided in central station work. All instruments should have bold and visible scales, the dials being vertical, so that it is not necessary to go up close to the switch board to take a reading.

Nearly all makers are now adopting the clock form. It is generally more troublesome to make instruments in this way, because the forces dealt with are so small that it is difficult to make the pivots free enough to give accurate readings. Instruments with horizontal dials can have suspended moving systems, but the advantage to the maker is generally more than counterbalanced by the disadvantage to the user. In addition to these requirements, instruments must not have their readings affected by changes of temperature, produced by the electric power wasted in the coils, or by change of temperature of the room in which they are placed, and they must not be affected by external magnetic fields, which are always strong and variable in direction in electric stations. For use at sea, there is another requirement still—that the movements of the vessel should not affect the readings. It is most important that station instruments should be always in circuit without using much power. If station power is taken at 2*d.* per unit, every watt lost in the instrument is equal to the interest on £1 at 7 per cent. Exacting as these requirements are, they have all, or nearly all, been already filled by the various leading instrument-makers.

Of the hosts of varieties of voltmeter and amperemeter that have been designed, only a few have survived ; and, curiously enough, the most successful form is one that was at first regarded with the most suspicion. The majority of these instruments are now made with soft iron cores acted upon by coils in various ways. Such instruments were considered unpromising because they cannot be made to give proportionate scales except by empirical means, and because magnetic hysteresis gives rise to errors. It is now generally realised that proportional scales are not important; and the errors due to hysteresis have been reduced by careful designers till they are no longer perceptible. To avoid these errors, all that is necessary is to arrange the soft iron parts of the instrument so that only a small portion of the excitation due to the coil is spent on the iron. This means either that the induction in the iron must be very low, in which case the forces dealt with are small, or that the excitation due to the coil must be large, in which case there is waste of power and heating. High induction thus cannot be produced with few ampere-turns, as the magnetic circuit must be chiefly through air. If it were chiefly through iron, the hysteresis errors would be considerable.

It would be of little use to illustrate the outsides of instruments, so diagrams are given which show the arrangements of the moving systems. The force acting on the moving system may be opposed by gravity or by springs. Most engineers have more confidence in gravity instruments; at the same time, springs are often very convenient, and must be employed for marine use. Their permanence has been frequently questioned; but, according to Kohlrausch, a good spring is absolutely trustworthy. Some springs creep, or take permanent or temporary sets, which may give rise to errors; but with care in selecting the material and in tempering, there should be no appreciable inaccuracy.

Fig. 1 shows the simplest form of soft-iron instrument. A soft-iron needle *a* is mounted on a pivoted arbor *b* inside a coil *c*, so that the field produced in the coil tends to turn it parallel with the direction of the induction. The movement is resisted by a small weight. This form of instrument was brought out some time ago by Miller, and different forms of it are made by Messrs. Crompton and Statter.

Fig. 2 is on the same principle, but the needle *a* is mounted on a vertical axis instead of a horizontal, and is held by top and bottom suspension wires, which also act as controlling springs. This is Lord Kelvin's marine voltmeter.

Fig. 1.

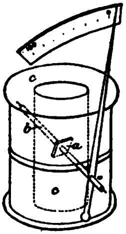


Fig. 2.

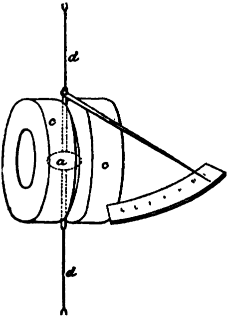


Fig. 3 shows an arrangement for giving a larger deflection in this form of instrument. The forms shown in *Figs.* 1 and 2 have a maximum deflection of less than a right-angle ; but that in *Fig.* 3 has a maximum deflection of nearly two right-angles, as the arbor must turn through two right-angles, to move the needle from the position shown dotted to that shown hard.

Fig. 4 is a modification of *Fig.* 1. In this, the field is made stronger by providing the coil *c* with an iron core *e*. A large range is secured by bringing the needle *a* back to a normal position by means of a spring and milled head. The increased range is, of course, obtained at the expense of direct-reading. This is known as the Cunynghame voltmeter and amperemeter.

Fig. 3.

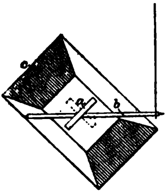
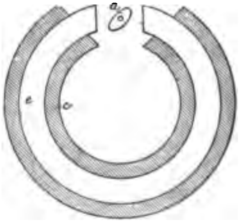


Fig. 4.



In the next form of instrument, the field due to the coil is modified by the presence of a fixed core or cores; and the soft-iron needle is arranged so as to tend to move from a weak into a strong field, the movement being opposed by weights or springs as before.

Fig. 5 is a diagram of the Edelmann voltmeter and amperemeter. A small strip of soft iron *f* is fixed in the coil, and the movable piece *a* moves away from the weak field in its neighborhood.

Fig. 5.

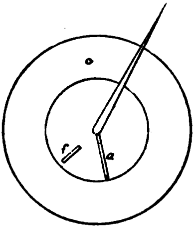


Fig. 6.

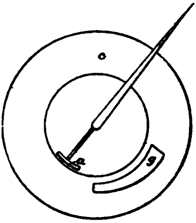


Fig. 6 is the Walsall instrument. Pieces of thin sheet-iron *g*, of a peculiar shape, are attached to the outsides of the coil to modify the field.

Fig. 7 is the core of an Evershed instrument. The field is modified by two short bars *h* placed inside the coil. The needle moves between them, and the ends are cut so as to make the field stronger at one side than at the other.

Fig. 7.

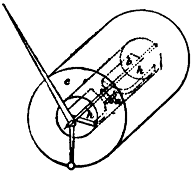


Fig. 8.

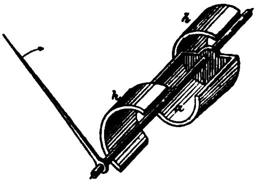
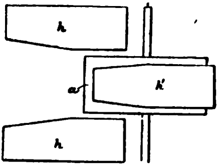


Fig. 8 is the core of one form of the Hartmann-and-Braun instrument; *h h* are fixed slips of sheet iron, and *a* is a moving piece which turns to get into line with them. There is a third fixed piece *h′* out-

Fig. 9.



side *a* to repel it. This is omitted for clearness, but is shown in *Fig.* 9, which is a developed view of the parts.

Figs. 10 and 11 show another form, with *h* and *h* omitted.

The forms shown in *Figs.* 5 to 11, have an important advantage over those in which the needle turns on a centre. They are not so easily affected by external fields, because the north and south poles of the needle move in the same direction. The needle, therefore, cannot set itself in the direction of any external field, as the direction of the needle remains the same throughout the readings.

Fig. 10.

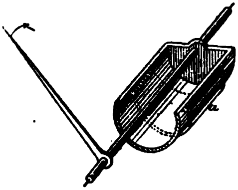
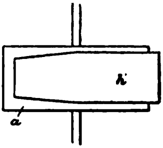


Fig. 11.



Figs. 12, 13, 14 show solenoids *c*, attracting soft iron cores into them. The movement is resisted by gravity in *Fig.* 12; which represents two instruments by Lord Kelvin and Dolivo Dobrowolsky. In Kohlrausch's instrument, *Fig.* 13, the movement is opposed by a spiral spring *i*.

The instrument of Professors Ayrton and Perry, Fig. 14, is remarkable. The movement of the hollow iron core *a* into the coil *c* is opposed by a spring as in the last case, but it is in the form of an Ayrton and Perry-twisted strip *j*. The core thus turns as it descends, and the index is attached to it, so that a small vertical movement of the core produces a large angular movement of the pointer.

Fig. 12.

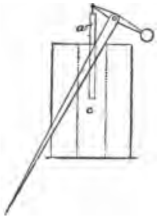


Fig. 13.

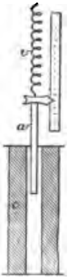


Fig. 14.

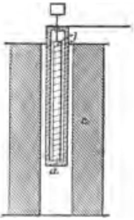


Fig 15 is a particularly ingenious arrangement, due to Messrs. Crompton and Kapp in England, and Professor Elihu Thomson in America. The needle *a* is either soft iron or magnetised steel, and it is free to move and take up any position.

Fig. 15.

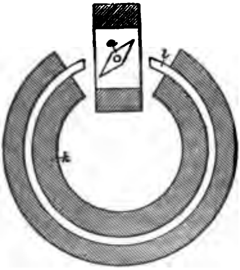
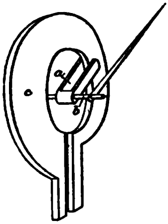


Fig. 16.

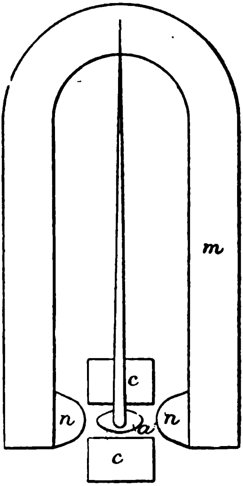


It is placed in a compound field, one component of which is produced by a coil *k* with a soft iron core *l*, and the other by a coil with no core. The field due to the coil with the iron core is not proportional to the current in the coil, as it depends also on the permeability of the iron, and this alters with the induction. The field due to the coreless coil is proportional, however, so the ratio of the two fields alters, and is measured by the needle.

Instead of modifying the field in such instruments as *Fig.* 5 by arranging fixed cores, the coil may be so arranged that the needle can move from a weak into a strong field. For instance, the arbor might be mounted eccentrically. A much better result is obtained, however, by Professor Elihu Thomson, in the instrument shown in *Fig.* 16. It is an amperemeter with only one turn of conductor *c*. The needle *a* is a sort of fork of soft iron, and it tends to move round to the narrow part of the conductor, where the field is stronger.

The next group depend on permanent magnets. The simplest form is an ordinary galvanometer with a permanent controlling magnet. Many instruments on the principle of the ordinary galvanometer have been made, but they all have the drawback of being easily affected by external fields. Messrs. Carpentier in France, and Professors Ayrton and Perry in England, sought to overcome this difficulty by using very strong controlling fields. Unfortunately, they went too far, and made the field so strong, and left so little room

Fig. 17.



for the deflecting coil, that it was apt to become hot. This form of instrument is still made in large quantities, especially in France. It is shown in *Fig.* 17, where *a* is the needle, and *m* the permanent controlling magnet, with polepieces *n n* ; *c c* are the two deflecting coils.

Almost the only survivor of the tangent galvanometer instrument, is Lord Kelvin's lamp-counter.

The soft iron needle of such an instrument as the Miller, *Fig.* 1, may be replaced by a hard steel magnetic needle. This form is generally used as an amperemeter, the coil being replaced by a single bar, against which the needle is mounted. It then tends to set itself at right angles to the bar, the tendency being opposed by gravity or springs, as the case may be. This form is made by Messrs. Paterson and Cooper, and Messrs. Latimer Clark, Muirhead and Company. Messrs. Siemens and Company make another form of the same instrument, in which the needle is suspended in the field due to a double coil. The force is balanced by turning a milled head, until the needle is brought back to the original position. Such an instrument is not direct reading, but has a large range, and does not need a dial specially engraved after calibrating. It is, however, easily affected by external fields.

The moving coil, or, as it is sometimes called, the Deprez-D'Arsonval galvanometer, can be used as a voltmeter either in its laboratory form, in which case it is hardly an engineering instrument, or arranged for commercial use. Mr. Weston's form is shown in *Fig.* 18. A strong permanent magnet *m*, embraces a coil of fine wire, *o*. Inside this there is a fixed soft iron core, *p*. Any current in the coil tends to turn it like the coil of a dynamo armature; this force is opposed by two hair-springs *qq*, which also serve to lead the electricity in and out. The moving-coil form of instrument has many advantages. It is not affected by external fields, and it is very sensitive, so that it can be made of high resistance, and can be left permanently in circuit without heating, or introducing temperature errors. Messrs. Carpentier have also introduced a form with wire suspensions instead of pivots, and with the magnetic field arranged so as to give readings through a large angle.

The Weber dynamometer still survives in the Siemens dynamometer, and in Lord Kelvin's balances. The Siemens dynamometer, *Fig.* 19, consists of a fixed

Fig. 18.

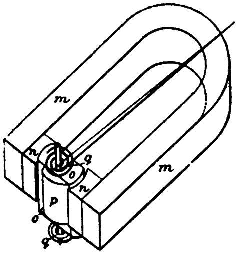
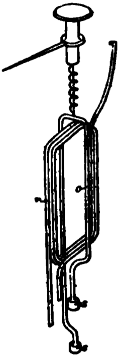


Fig. 19.

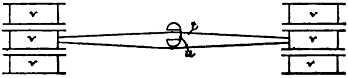


and a moving coil, *r* and *o*, suspended at right angles. The moving coil tends to arrange itself parallel to the fixed coil, and the force is resisted by a spring and milled head. The contacts to the moving coil are made by mercury cups, *s s*.

This instrument is not direct-reading, and is influenced by external fields, but is still largely used in alternate current work.

The Kelvin balances are, really, carefully made scales, for weighing the force exerted by coils carrying currents. The principle is shown in *Fig.* 20. The great difficulty in such instruments, especially for use as amperemeters, is to make the connections without interfering with the accuracy of the balance. Lord Kelvin has overcome this, by suspending the moving system by a number of fine wires. These can carry large currents, and are much more flexible than a single thin strip. These instruments are not direct-reading, but that is a small matter, as they are intended not as station or installation instruments, but as secondary standards for those who have no standard cell gear. Some forms are, however, made direct-reading, for engine-

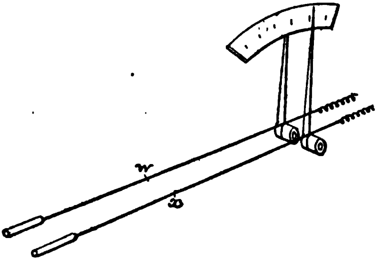
Fig. 20.



room use. The beam *t* is supported by the ligament *u*, made up of fine wires ; *v v* are the coils.

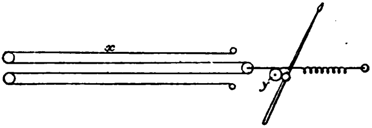
The next form depends on the heating of a wire by the current in it. *Fig.* 21 shows the first practical form of this instrument, due to Mr. G. M. Hopkin. Two

Fig. 21.



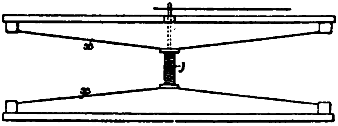
wires *w x* of the same material are used. The expansion of one, *x*, moves an index, and this wire carries the current. The other, *w*, is arranged so that its expansion moves the dial. This is necessary, as, without compensation, the reading would depend partly on the temperature of the air where the instrument happened to be. In the form shown, the reading depends on the difference of the temperatures of the two wires, not on the absolute temperature of one of them. By far the best known and most used of the hot-wire instruments, is that of Major Cardew. In this, all the details have been worked out with the greatest care, and a thoroughly commercial instrument has been produced.

Fig. 22.



The wire x is made so long that the instrument can be used for 150 volts, and the readings are increased by multiplying gear y. The arrangement is shown in *Fig.* 22. Compensation should be made for change of temperature due to the heating of the instrument by the current, and for change of resistance due to external variations of temperature. The first correction is made in some instruments, by making the case which holds the wires of brass and iron tubes so proportioned as to have the right expansion ; and the second is omitted. It is said that the reduction of the viscosity of the air at the higher temperature compensates for the increase of resistance due to the instruments being placed, for instance, in a stoke-hole. In other instruments, the index is brought back to zero by a small screw, to eliminate the error due to the rise of temperature by internal heating.

Fig. 23.

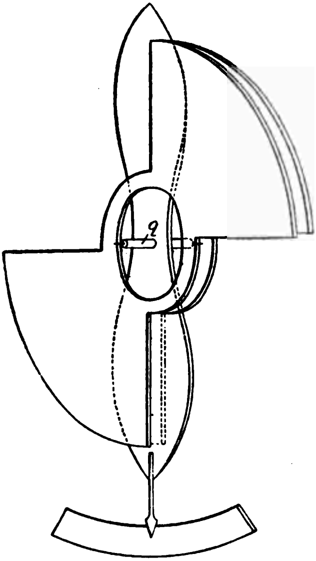


Professors Ayrton and Perry have brought out a hot-wire instrument, in which the expansion of the wires x allows them to sag, and the sag is measured by one of their strip springs j. This ingenious instrument is shown in *Fig.* 23. The wires may be coupled in series so as to be used for 100 volts, or in parallel for testing batteries, and such work. It is difficult to compensate this form of instrument for temperature errors. If the body is made of metal or alloy with the same temperature coefficient as the wire, the expansion error can be corrected ; but the resistance error still remains, as in the Cardew, and, of course, the body of the instrument takes some time to heat.

Messrs. Hartmann and Braun make a hot-wire instrument, in which the sag of the wires allows the spring to turn the index. This form can be compensated for temperature in the same way as the Cardew.

The next form of instrument involves the use of a standard cell. A standard cell is sometimes used, in conjunction with a reflecting galvanometer and a set of resistances, or even a stretched wire, for measuring both pressures and currents. This arrangement can hardly be considered applicable to commercial use. Mr. Edison has, however, made voltmeters which contain the necessary resistances and standard

Fig. 24.

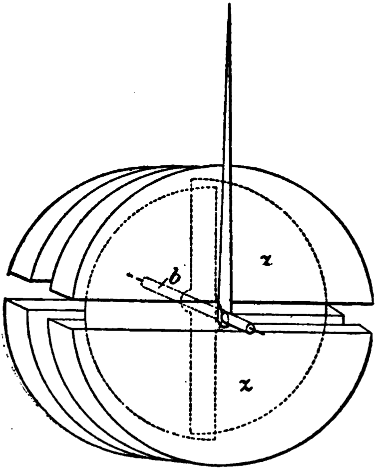


cell inside the case. They are not direct-reading, as the resistance has to be adjusted till the needle comes to zero. Such voltmeters may be made very accurate, but there is some uncertainty as to the trustworthiness of standard cells subjected to such continuous rough usage.

Voltmeters are also made which depend on electrostatic action. *Fig.* 24 represents Lord Kelvin's electrostatic voltmeter for high pressures. It is practically a quadrant electrometer, with a horizontal arbor resting on knife-edges, and a gravity control. This form is not sensitive enough for such pressures as 100 volts, so Lord Kelvin has designed another form with a wire suspension. In this electrometer, instead of one quadrant, there are several, so that enough torque is obtained to twist the suspending wire. If a single cell were used, the suspending wire would have to be very fine or very long, and this would make the instrument unpractical. The use of several cells admits of a suspension of reasonable thickness. This instrument has a horizontal dial, but it is provided with a mirror, so that the readings are visible in front, if it is on the level of the eyes.

Fig. 25 shows the Author's station voltmeter. Instead of quadrants, it has half-circles, two pair being used for symmetry. A gravity control is employed, and the

Fig. 25.



moving system is so shaped that the index traverses the whole scale between, say, 1,800 and 2,200 volts. This instrument is useless for low pressures.

In describing these instruments, continuous currents have been alone considered; and it will be best to discuss alternate current instruments by themselves.

Alternate-Current Voltmeters and Amperemeters.

Many instruments already described will do equally well for continuous and alternate currents. This is the case more especially with amperemeters. Of course all instruments with permanent magnets are out of the question for alternate-current work. A soft iron amperemeter which is so arranged that the iron does not produce hysteresis errors with continuous, will generally work with alternate currents, if the iron is laminated so as to avoid Foucault currents. In order that such an instrument shall work correctly, it is necessary that the force at every part of the period should be proportional to the square of the current. If the induction is strictly proportional to the current the reading is thus correct. If the induction is appreciably affected by hysteresis there is an error. If there are any Foucault currents in the iron core, or in the brass work of the instrument, the iron is not fully magnetized, and the reading is too low.

In order that a voltmeter should be available for alternate currents it must be made with no appreciable time-constant, else it reads too low. It can, of course, be calibrated for a particular frequency ; but that is not of much use, as stations do not keep accurately enough to stated speeds. Various methods have been proposed for overcoming this difficulty. The simplest is to use an instrument on the Weber dynamometer principle, either wound with wire of a very high specific resistance, or arranged with a non-inductive resistance in series with it. This arrangement involves too great waste of power, and most electro-dynamometers are not direct reading. Mr. Gray has proposed to arrange Lord Kelvin's balances so that the two coils repel each other. The mutual induction of the two parts of the circuit then largely compensates for the self-induction of the two coils in series. Mr. Evershed and the Author have proposed to compensate for self-induction by means of condensers, and by other methods involving small choking coils. The condenser method reduces the error, but there is still a small variation if the frequency varies. Lord Kelvin has recently introduced an electrometer made sensitive enough to read down to 60 volts. This instrument, which has been already noticed, is most convenient, as it takes no power, is not affected by external fields, and has no temperature errors. Its only drawback is its horizontal dial. By far the most generally used alternate current voltmeter is the Cardew. It acts just as well with alternate as with continuous currents. Most alternate stations run at 1,000 or 2,000 volts. The electrostatic form of instrument is therefore much the best, as it is easily made, and takes no power. Such instruments will of course work equally well with alternating or continuous currents.

One of the most complicated questions in connection with alternate currents is the measurement of power. The ordinary wattmeter as used in continuous-current work consists of a fixed and a movable coil. One is of thick wire and is in series with the current, and the other is in shunt and takes a current proportional to the pressure. The force acting on the moving coil is then proportional to the product of the pressure and current, that is to say, to to the power. This instrument is exceedingly useful in incandescent-lamp testing, but it demands a correction. If the pressure coil is put in shunt to the lamp only, the current coil takes the current of the lamp and the current of the pressure coil, so that the reading is too high. If the pressure coil is arranged in shunt to the lamp and current coil, it has the extra pressure due to the drop over the resistance of the current coil, so that the reading is again too large. In fact the wattmeter really reads the power spent in the circuit to be measured plus that spent in one of its own coils.

This error can be compensated so as to make the instrument read correctly, but this compensation is necessary only when small powers are to be read. Reference for particulars may be made elsewhere.[1] In measuring alternate powers another error comes in, due to the time-constant of the fine wire or pressure coil. This reduces the current in the pressure coil, so that the reading on non-inductive circuits is too low, and also makes it lag, so that the instrument reads high on inductive circuits. Though an ordinary wattmeter, as used for continuous current, is not suitable for alternate work, there is no real difficulty in making an instrument which is sensibly correct with alternate currents. The current coil should produce a strong field, and the pressure circuit should have comparatively few turns on the moving coil, a non-inductive resistance being arranged in series with it. There is an undeserved prejudice against the dynamometer wattmeter. On the other hand, the same in-

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[1] B. A. Paper, 1887.

strument, arranged so as to have greater errors and called a split dynamometer, has till lately been treated as accurate. Several methods of measuring power by electrostatic instruments have been proposed. The electrostatic analogy of a dynamometer wattmeter cannot be found, for the mutual attraction or repulsion of two electrified bodies is as the square of the difference of potential, while in the dynamometer the force is as the product of the current in the coil. All methods of measuring alternate power electrically involve non-inductive resistance, and therefore they all have the same error from such resistances not being accurately non-inductive.

There is no difficulty in making a resistance which has no sensible time-constant. The Author's form of wattmeter has a moving system, consisting of a few turns of wire, with a non-inductive resistance in series, and this form of instrument is accurate within the limits of observation. Put on an inductive circuit with 100 volts and 5 amperes, which was known to have a loss of about 12 watts, the instrument read within 2 watts of the calculated power. On a condenser taking 2,000 volts and 3 amperes, or an apparent power of 6,000 watts, it gave no deflection. If a little care is taken in designing, so that there is no appreciable self-induction, and if a little trouble is taken in manufacturing, so that there is no leakage across the resistance even under pressures of several thousand volts, alternate-current power can be measured as easily and as accurately as in the case of continuous currents.

Though the dynamometer wattmeter is the only instrument that can be discussed in a Paper devoted to commercial measurement, mention may be made of the various other methods proposed. The application of the electrometer is due to Professors Ayrton and Fitzgerald. Two readings are necessary. The errors in this method are likely to be large, because the power is the difference of two comparatively large values determined by the two readings, so that a small percentage error in the reading means a large percentage error in the power. In order to reduce this error, a large shunt resistance must be used, and this at once makes the method unpractical. For instance, if the power going into a transformer taking 2,000 volts and 10 amperes is to be taken, a resistance that also takes 2,000 volts in series with it wastes some 27 H. P., and demands a dynamo giving from 2,800 to 4,000 volts. Messrs. Blondlot and Curie and the Author have made forms of direct-reading electrostatic wattmeters which overcome this difficulty. They give accurate readings with comparatively small resistances in shunt. They are, however, not so convenient to use as dynamometer wattmeters. Messrs. Sumpner and Ayrton and the Author independently published a method involving three voltmeters. The three instruments do the work of the single direct-reading electrometer wattmeter, so this method is of purely scientific interest. The power is found by subtracting the sum of two readings from the third reading, so that if this difference is small in comparison with the readings, large percentage errors may creep into power determination. Large resistances are therefore again necessary, and the method is of little practical use. Dr. Fleming has much improved the triple-instrument method by working with currents instead of pressures. By this means he avoids the necessity of, for instance, having to use 4,000 volts in testing a 2,000 volt transformer ; and he makes it possible to use the three-instrument method in central stations. It is, however, useless to employ complicated methods of measuring power when a simple one is better. The prejudice against the ordinary wattmeter has no real foundation. It is easy to make calculations involving R and L, and to work out the errors due to L, thus making out that the wattmeter is not accurate. But if any one will take a real instrument, designed with a little care, and substitute the approximate values of R and L, he will find that he has been straining at a gnat. In addition, it must be remembered that all the other methods mentioned have errors due to L, and frequently othèrs in addition.

RESISTANCE.

Electric-light engineers seldom have to measure moderate resistances, and resistance measurements are always described in text-books. It may not be out of place, however, to comment on the absence of resistance-boxes meeting electric-light requirements. The comparison of electrical forces can be made with greater accuracy than any other kind of measurement. A good chemical balance will weigh within one in a hundred thousand, but electric pressures, currents or resistances, can be compared within one in a million. Electrical measurement is less accurate than weighing, solely because of the difficulty of preparing constant standards. Resistance-boxes can be made with great accuracy, and can also be easily checked; the result is that an engineer who is quite satisfied with a voltmeter which may be 1 or 2 per cent. wrong, insists on having a bridge which is accurate within one in ten thousand or a hundred thousand, costing well on to £30. Apart from the excessive cost of such apparatus, it is not suitable for practical work. Plugs are the best means of making good contacts, if they are well made and are kept thoroughly clean. The plugs of most resistance-boxes are not well enough made, and are not kept clean. Resistance-boxes for commercial work should therefore be made with switches. A switch can be made to give a very good contact; but even if it did not, a switch-box still comes out better than most plug-boxes. Take an extreme case. Suppose a post-office bridge with twelve plugs in the adjustable part, each with a constant resistance of, say, 0.01 ohm, the total contact resistance varies from 0 to 0.12 ohm. A switch-box to give the same range has four switch contacts. Suppose the resistance of each to be 0.02, the total contact resistance is 0·08, but this is always in circuit. The errors are due, not to the resistance of the contact, but to their variations, that is to say, the error is of a higher order. The box can be arranged so that the resistance of the connections and contacts are all allowed for in the one ohm coil ; this cannot be done in the ordinary arrangement, so that the switch system is very much more accurate. In addition to this it is very much more rapid in use. With a dead-beat galvanometer and a switch resistance-box, a resistance can be taken in a few seconds instead of some minutes. The ordinary resistance-box is made of the post-office pattern to suit telegraph and not electric-light requirements. Instrument-makers should therefore turn their attention to apparatus for measuring very high and very low resistances. For low resistances it is necessary that the contacts should not be in the circuit to be measured, so that some feeler arrangements like those due to Mr. Heaviside or Lord Kelvin are necessary.

More progress has been made in measuring small conductivities, such as those of the wiring of installations. One method is to use a battery of some thirty cells, to take a reading with a galvanometer in series with, first, a standard resistance, and second, the wiring to be tested. From these readings the insulation resistance is obtained. The chief drawback to this arrangement is the weight of the apparatus. There is great need of some cell which can give a volt or so, and does not weigh more than perhaps a fraction of an ounce. The current needed from such cells is, of course, exceedingly small, a-tenth of a milliampere for instance, and there is no reason why they should not be very minute.

Some years ago Lord Kelvin brought the ohmmeter before this Institution. It consists of a magnetic needle which is free to turn. This is acted on by two fields ; one is due to a pressure, and the other to a current coil. The needle takes up a position depending on the direction of the component of these fields, so that it indicates the ratio, and the instrument can thus be graduated in ohms. Mr. Evershed has brought out an ingenious apparatus consisting of an ohmmeter and a tiny dynamo. The little dynamo develops the pressure, thus avoiding the necessity for cells, and the ohmmeter measures the resistance. This apparatus is used for testing insulation. Messrs. Hartmann and Braun have also brought out several forms of insulation testing apparatus. Some of these also have small machines ; but in one case a bell is rung through different resistances, and in another an amperemeter is put in series. This may at first seem rough, as the speed of turning may alter. But if the operator always tries to turn it 60 revolutions per minute, the speed will not vary more than 10 or 15 per cent., whereas the insulation resistance of a given installation frequently varies 100 per cent. from day to day owing to minute leaks over damp surfaces. For ordinary work such an arrangement is therefore accurate enough.

METERS.

By far the most important instrument of all is the meter. The pressure and current indicators in a station cost little in comparison with the heavy plant; but the question of meters is most serious because one must be provided for each customer, so that they are very numerous. The requirements are that the meter should be accurate throughout its load. For years Supply Companies, especially those using alternating currents, have been obliged to content themselves with meters in whose favor all that can be said is that they go faster if the load increases. The enormous difference in the revenue due to inaccurate meters does not seem to be fully realized. A meter that reads 2 or 3 per cent. wrong, may make all the difference between working at a loss or at a profit. It may be urged that inaccuracy does not matter, because it tends to average about right. This is, however, very doubtful. The inspector is not likely to pass meters that read much too high at any parts of their range; and most give too small readings at light loads. It is most advisable that meters should start with a single lamp, out of at least 100. Very few motor meters come near this. Suppose a house is wired for 100 lamps, and its average load is equal to 10 lamps always on; and suppose one lamp is burning all day in a dark passage, but is not counted by the meter. The error is 10 per cent. against the Supply Company. If the Company were to replace the meters by some accurate form, they would increase the revenue 10 per cent. with no extra expenditure, which is enough to turn a failure into a brilliant success. Errors due to temperature variations may frequently be 10 per cent. or more, if copper is used. As a matter of fact, copper is often used in some forms of meter, owing to the high resistance of alloys with low temperature co-efficients. Meters which are correct when adjusted at the some temperature, may vary very largely, if one is placed in a cold cellar and the other in a warm front hall, or in a kitchen.

It is most important that the meter should not itself waste power. If the cost of extra energy is taken at only 2*d.* per kilowatt hour, every watt lost in the shunt circuit of a motor meter costs 1*s.* 6*d.* per annum. Taking interest and depreciation together as high as 7 per cent., this means £1. That is to say, the price of the meter must be considered as increased by £1 for every watt taken in the shunt circuit; so that a £15 meter which has no continuous waste is to be preferred to a £5 meter that takes more than ten watts continuously. The various sources of error can best be discussed in connection with particular forms of meter. It is questionable whether any parts of a meter should be allowed to go at high speeds. A motor meter with an armature running at 1,000 revolutions per minute will probably wear itself out soon, but it is difficult to say whether the speed should be limited to something like 100 or to about 10 per minute. The balance of a watch performs 300 reciprocations per minute for many years without perceptible wear. Other things being equal, of course low speeds are best. A meter should not cause a drop by setting up a perceptible back pressure, or by absorbing too much power in resistances. The loss of 1 per cent. means not only a waste of 1 per cent. of the energy paid for, but that the lamps will be run some 5 per cent. under candle power, so that the consumer gets 5 per cent. too little light, and cannot run his lamps properly. A quarter, or, at the very most, half a volt in a 100-volt installation is all that should be allowed as full-load drop in the meter. A meter should be direct-reading ; preferably it should have an index like that of a gas-meter. This is not a matter of real importance; it is a concession to prejudice. When gas came into use, gas chandeliers were made, and it was pretended that candles were being burnt. Now that electric light has been introduced, the fittings are altered a little more, and it is pretended that gas is being used. The chief advantage of direct-reading is that it allows the consumer to see how much he is using, and this gives him confidence. It is still usual for makers to send out meters whose readings have to be multiplied by a constant. This slovenly practice will probably soon die out. It used to be common in the case of volt and amperemeters, but is now discarded in instruments of the best types.

It is questionable whether mercury is admissible in a meter. Mercury appears to give trouble when used in connection with a commutator. The surface is apt to become oxidised, and the mercury separates into a number of minute globules. Many forms of meters have mercury whose surface is not changed, the moving part being wholly immersed. In this case the mercury is not likely to become "dead." The next trouble is amalgamation. Even the vapor of mercury will amalgamate. The train and all the mechanism must therefore be made of iron, steel or nickel. Nickeled brass will stand for some time, but electro-deposited nickel is so porous that it is questionable whether mercury will not eventually destroy any meter containing brass, tin or copper. These statements as to the action of mercury are open to contradiction, and the results of experience extended over some years would be valuable.

All the parts of the meter should be strong, so that the mechanism is not likely to go wrong. All sorts of watchwork are to be discouraged. A meter containing any kind of delicate mechanism may work on the test-room table; but it is quite another thing when it is in practical use. At present, while electric light is, to some extent, a novelty, the housing of the meter receives some little extra attention; but it will soon share the fate of the gas-meter, and be put in any out-of-the way cellar, where it will be exposed to dust and damp, and perhaps traces of corrosive gases. In addition to this, most meters are slightly warm, and this attracts all sorts of insects, which can usually find entrance if the cases are not very carefully closed. Many meters are stopped by insects; and it is foreseeing such contingencies and providing for them, that constitutes the principal difficulty in developing a new industry.

Above all, it is necessary that meters should be cheap. There is no difficulty in designing a beautiful meter which shall cost £20 or £40; but that is not the problem. What is required is a meter which is accurate enough for commercial use, and which costs as little as a gas-meter, or even less.

Electric meters may be divided into several classes, and these will be taken in order.

The chemical, or electrolysis, meter is largely used in America for direct current work. A low resistance is inserted in the main circuit, and a high resistance in shunt to it. In the high-resistance circuit a voltameter is inserted. Mr. Edison uses zinc in zinc sulphate for his voltameter, and appears to get very good results. If amalgamated zinc is used, an electromotive force of a millionth of a volt on the voltameter is enough to work such a meter; there should be no error if the zinc sulphate solution is used diluted so that it remains homogeneous, and if the plates are well amalgamated. This meter is not used in this country. It has only one drawback, and that is that the deposits have to be weighed. On the other hand, it has the advantage of cheapness in manufacture, and is not apt to get out of order. It is then a question whether the trouble of weighing is not more than paid for by the gain in first cost. If the meter costs £5 less than one with an index, the interest on the saved money taken at 7½ per cent. is 7*s.* 6*d.* a year. If the inspector calls once a quarter, it will pay to use this form, if the weighing takes up less than about 2*s.* worth of his time. It is not at all likely that his time would be so valuable as this. There is, however, a great prejudice against such meters.

For alternate currents aluminium may come into use. This is the only metal which cannot be deposited electrolytically, so that the quantity of electricity passed can be found from the loss of both plates. It is difficult, however, to obtain aluminum quite free from silicon and other impurities, and the plates are apt to dissolve slowly even when there is no current. Mr. Wright has used copper voltameters in series with high resistances as meters in series distribution. Such a meter really integrates the pressure, and, as the current is constant, the energy taken is readily found.

The largest class of meters depend on small motors. The motor is generally arranged to do work on a brake. The brake usually employed is an Arago disk, or some sort of fluid friction arrangement, such as a fan in air or in a liquid, as for example mercury. The meter may be coupled up in many ways; the armature and the field magnets may be in the main circuit, or may be in shunt circuits across the pressure terminals of the house and so on, or permanent magnets may be used for the field. Alternate current meters again demand special motors. The meter may have a number of armature turns and a commutator, or it may be of the one turn type which demands no commutator. To make a meter accurate there must be a law underlying it. If a voltmeter does not give a straight line law, the scale is graduated to read correctly ; it would be hopeless to take such a voltmeter as most of the soft iron instruments described, and to tamper with the shapes of the parts until a straight line law was obtained ; and no one who had experience of instrument manufacture would have confidence in the result. In fact each of the instruments would have to be manipulated individually. In practical work, therefore, when accuracy is required, the scale is altered to fit the instrument. In a meter this can not be done. It must be made to give a straight line law ; or in other words, a meter must be based on laws in accordance with which it moves its train at a speed proportionate to the current or power as the case may be. It must not follow some other law and be manipulated till it gives readings which may be nearly right, but are probably still very wide of the truth.

Motor meters, with the field in series with the armature, work under disadvantage. The brake in this case is generally fluid friction. There is some doubt as to what law fluid friction follows. It is at times said that the force varies as the speed, and at others that it varies as the square of the speed. According to one theory the force varies as the speed as long as that is small. When the speed reaches a certain value vortices are produced, and the force varies as the square of the speed. A series meter is correct only when the torque varies as the square of the speed, and the power is the cube ; at low readings it will be against the Supply Company. If the torque is the sum of two torques, one of which varies as the speed and the other as the square of the speed, the meter will work correctly if its field has shunt-and-series windings in the proper proportions. Some series meters are arranged with shunts, but the object is generally understood to be to overcome the difficulty of starting. In addition to the fluid friction, there are the frictions of the pivots, and of the film of oxide on the surface of the mercury, when that has to be overcome. A series meter has only one-ten-thousandth part of its full load torque available at 1 per cent. of the full load. The shunt series arrangement has a much greater torque. The whole question of fluid friction in meters demands investigation. Some fluid friction meters are series wound, some have constant and some compound fields. They cannot all be right. There is still another objection to series and compound fields for direct current work, and that is that errors arise through hysteresis. If the meter has been reading at full load, and the load is greatly reduced, it will read too high. The Arago disk and all other arrangements involving

Foucault currents take torques proportional to the speed, and power proportional to the square of the speed ; not torque proportional to the square of the speed and power proportional to the cube, or to the speed. This point is of great importance in the theory of meters, more especially as it is frequently incorrectly stated. Even the French Commission, when they awarded the prize of F. 10,000, were inaccurate on this point. The difficulty of starting at small loads occurs in all meters following square laws. If, for instance, 100 amperes yield torque which affords a reasonable speed for the full load of the meter, then one ampere would give only one-ten-thousandth part of the torque, as just explained, and that is generally too small to start the meters. A shunt round the field can never be the right way of starting a meter. An extra armature-current is what is wanted, but that cannot well be arranged economically, at least in continuous-current meters. No residual torque arrangement can ever be accurate, however, because the starting friction is always much greater than the stopping friction. If the meter has a permanent torque which will just start it, it will never stop. If the permanent torque just allows it to stop, it will not start without an appreciable load.

Faure appears to have been the first to use a one-turn motor with mercury, but as his meter has not come into commercial use it is unnecessary to describe it.

Mr. Ferranti uses a series one-turn motor meter. This inventor has struggled for years against difficulties inherent in the series motor. To make it start, he excites the field partly by a shunt circuit arranged across the terminals of the installation ; or, as it may called, a pressure circuit. The brake is supplied by the friction of the mercury and mechanism. If the torque necessary to overcome this friction varies as the speed, the field should be shunt-wound entirely, not partially. Mr. Ferranti appears to have found this out by experiment, and his latest form of meter has a constant field. In the form with the shunt field, there is a temperature error due to the variation of the resistance of the shunt.

The Teague meter is on the same principle. In this case also a one-turn, or unipolar, motor, is employed. The armature has a disk with a radial current. The outside is turned down to run in mercury, and the inside runs in a central mercury cup. It is thus a disk with radial current and mercury connections. The field in this meter is also wound partly with a constant pressure shunt, and partly in series with the armature. The shunt, as in the case of the Ferranti meter, makes the torque more nearly right at very small loads ; but the series winding, unless the brake-torque increases faster than the speed, seems to be wrong.

Among constant field motors Mr. Ferranti's permanent magnet form has already been mentioned.

In the Hookham meter, the field is a permanent magnet. This arrangement is most important as it absorbs no power. The armature has several turns, and a commutator whose sections dip into mercury. The large meters are shunted by low resistance, so that a portion only of the main current is carried by the armature. This meter has no appreciable temperature error, as the low resistance shunt is platinoid, and the armature turns are wound on the Arago disk, so that it is at the same temperature, as well as of the same material, so that the effects of change of resistance cancel each other cut. The mercury commutator contacts seem to be the only drawback to this type.

The Hartmann-and-Braun meter has a one-turn armature in the form of a disk, but the whole of the disk is not in the field, so that it acts both as armature and brake. The contacts are made by mercury cups, but the immersed parts are continuous. The field magnet is excited by a pressure current. This is, of course, a disadvantage, as it means a continuous waste of power.

The next form is due to Professor Perry. The moving system is a copper disk. This is submerged in mercury, so that the frictional resistance at the surface causes little trouble, as the rotating part is of small diameter where it emerges from the mercury. The movement of the armature is opposed by Foucault currents, but they are in the disk itself, not in a separate brake. The meter is the same in principle as the Hartmann-and-Braun, but the details are different. The field is notched so that if the armature is still, the current spreads uniformly, but if the disk can move, it rotates at such a speed that the current leaves those parts of the armature which are in the strong field, and flows where there are gaps. Similarly, in the Hartmann-and-Braun meter, if the armature is still, the current will flow chiefly between the poles ; but, if the armature is free to rotate, it will go at such a speed that the current flows round so as to avoid the field. This is merely another aspect of the Foucault current explanation ; but it is always advisable to look at things from as many points of view as possible. Professor Perry's meter has a very small armature, with little friction. It should therefore start with a small fraction of the full load, and should move very slowly at all times.

Though this meter has been taken in order, and has been described as a modification of the numerous motor meters, it must not be forgotten that, in a sense, Professors Ayrton and Perry have invented nearly all the types of motor meters now in use. Some nine years ago they laid down the principles involved in their construction with perfect clearness, and though motors had been previously described, it is questionable if any one until then clearly understood the matter.

The next form to be discussed is the joulemeter, or, as it is often inaccurately termed, the wattmeter. So far coulombmeters have alone been described. It has often been pointed out that a joulemeter is better because the consumer is supposed to be charged by the energy used, not by the quantity of electricity. On the other hand, it is urged that the pressure is kept constant, so that a coulombmeter is all that is needed. The pressure is seldom exactly as it ought to be, and the joulemeter is therefore really preferable from that point of view. To make charges really fair to the customer, the meter should read according to the light given by the lamp, that is to say, it ought to run about 5 per cent. slow for every 1 per cent. the pressure is below the normal, as the light decreases in about that proportion; and should run very slow, or even perhaps backwards if the pressure is above the normal, as the Supply Company is then seriously reducing the life of the consumers' lamps. Such meters as these are, of course, impracticable; so, other things being equal, the joulemeter is best. A joulemeter, however, must have a high-pressure circuit in which power is being wasted continuously, and it is then a question whether it is not better to use a coulombmeter, which sometimes means a loss to the one party and a gain to the other, than to have an accurate meter which involves a dead loss. Take as a sample case, a house with fifty 30-watt lamps, the full load is 1,500 watts, the average load, say 125 watts. If the Company runs the circuit at 101 volts instead of 100, and charges by a coulombmeter at 8*d.*, per Board-of-Trade unit, the price is 2*s.* per day. If the joulemeter is substituted the charge is increased 1 per cent. If the joulemeter itself absorbs 10 watts, the cost of this, taking extra power at 2*d.* per unit, is 0.48 per day, so that the customer has to pay more, and the company loses too. It is possible 10 watts is an outside estimate, and it is also possible that a small cut-out, which opens the pressure circuit when no lamps are in use, may be employed.

In the Thomson-Houston meter, invented by Professor Elihu Thomson, the armature is retarded by an Arago brake, which is of large diameter and has three magnets, so that it is strong. The field magnets of the motor are two stationary coils which have no iron core, and the armature is made up of coils of fine wire which form the pressure circuit. The resistance of the small commutator does not interfere with the accuracy of the instrument, as it is in series with some thousands of ohms. The meter seems to be almost perfect, but has some drawbacks. It is a question whether the omission of iron in the field does not involve too great a loss in the fine wire circuit or excessive drop in the series coils. To reduce this is only a question of workmanship. The same form of meter is available for continuous or alternating currents, which is a great advantage, and tends to cheapness of manufacture.

The Hummel meter is the same as the Thomson in principle. The Foucault currents are produced by an electro-magnet, however, which converts it from a joule-meter into a coulombmeter. It is also possible to get much greater damping by means of an electro-magnet, so a lower speed may be employed. As has been already mentioned, it is an open question whether it is best to measure the energy or the quantity ; but by coupling the electro-magnet in series with the armature, Mr. Hummel makes it difficult to compensate for temperature. For instance, suppose the temperature to rise enough to increase the specific resistance of copper 10 per cent. The field being in the main circuit remains constant. The armature current falls 10 per cent., so that the torque is reduced 10 per cent. The field of the electro-magnet also falls 10 per cent., and the resistance of the copper disk increases 10 per cent., so the Foucault currents are reduced 20 per cent., and the meter therefore increases in speed 10 per cent.

In all the meters described, so far, the speed of the motor has been controlled by some sort of break. In a meter designed by the Author the motor is in shunt to a low resistance. The motor runs loose at such a speed that its back electromotive force is equal to the fall of pressure over the resistance. This form of meter has several advantages. The armature never takes a large current, so that the brushes are small and the friction is trifling, and mercury contacts are unnecessary. The armature is also light, as it has no copper disk, and it wound with aluminium. The chief advantage, however, is the ease of starting. Suppose the armature will start with 0.1 ampere, and suppose the armature resistance is twice the low resistance in shunt when a single lamp is turned on, taking, say, 0·3 ampere, the armature takes 0·1 ampere and starts. A brake-meter might also be made with the same resistance, and it would take 0·1 ampere with one lamp on, which in most cases would not start it; but at full load of, say, one hundred lamps, it would take the current of thirty-three, so the brushes would have to be large enough to carry 10 amperes; in fact, mercury becomes essential. The free motor meter, however, still takes only about 0·1 ampere, so its brushes can be very small strips of platinum or silver giving little friction.

Many meters described are available for alternate currents. The Ferranti meter, for instance, is made with a laminated magnet; but, as already mentioned, difficulties arise because the torque does not vary as the current. The same remarks apply to the Teague meter wound for alternate currents.

The Thomson and the Schuckert meters are perfectly applicable to alternate currents. There is, of course, an error due to the time-constant of the fine wire circuit; but this is practically negligible. This is one of the very few meters that follows a simple law, and may therefore be considered trustworthy for alternate currents.

Many alternate-current motor meters, unfortunately, are still things that go round when the load is large enough, but whose speed does not appear to bear any simple relation to the current or power.

There are several alternate-current motors which have no electrical connection to the moving parts. Of these the best known is the Shallenberger, which has been most successful in America. The moving system is a small disk of iron. There are two coils round it, arranged at a small angle. One of these is in the main circuit, and the other is a closed coil. The current in the main coil magnetises the iron, and also induces a current in the closed circuit. This latter current lags a little. The main current, therefore, induces poles in the disk, and the secondary then acts on these poles and attempts to set the disk in a new direction, thus rotating it. The movement of the disk thus depends on angular hysteresis. If the iron is replaced by a copper disk of some thickness, Foucault currents are produced in it which convert it into a sort of solenoid, so that it is acted on in the same way as the iron, except that it moves in the opposite direction. The torque of this meter, when it has an iron disk, is thus approximately as the square of the current. Its secondary current also varies approximately as the frequency, so that the torque also varies as the frequency. If a copper disk is used, the torque varies approximately as the square of the current and as the square of the frequency, as the currents in the disk and in the secondary both vary approximately as the main current and as the frequency. The departure from the square law is because the product of the self-inductions of the open and closed circuits is much less than the square of the mutual induction. This is, of course, also the cause of the torque.

In Mr. Wright's meter the main current magnetises the field, but closed secondary coils are wound on the pole-pieces, so that the magnetization of the ends lags a little. This causes rotation of an iron or conductive disk. This meter follows the same laws as the Shallenberger, just described. In the case of the continuous-current motor meters, it was seen that the meter must either have a pressure circuit or a permanent magnet, otherwise the torque is not proportional to the current or power.

In alternate currents permanent magnets are obviously useless, so a pressure circuit is necessary to give the right law. Alternate-current meters of the kind just described really require two currents differing in phase, perferably by a quarter of a period. It is not in any spirit of criticism that these remarks are offered on this and other forms of meter. It must be enormously difficult to make a meter work, whose torque varies as the square of the current, and as the frequency or as its square. In fact, a meter whose readings depend on the frequency cannot be accurate, for all the station has to do, in order to convert a heavy loss into a splendid profit, is to weaken the fields on their dynamos and run them faster. Though a station engineer would hardly be dishonest enough to run fast, he would probably be careful not to run slow. It is also but fair to mention that these criticisms are based on theoretical considerations only; the Author has no figures to show that one form of meter is worse than another.

An important class of meter consists of a clock which is made to go fast or slow by acting on the pendulum. This form of meter is also one of Professors Ayrton and Perry's numerous inventions. The best known form is the Aron meter, an instrument which has deservedly come into extensive use. In this there are two clocks carefully timed. They work an index-train by means of differential gear, on the same principle as that frequently used on tricycles. If the clocks go at the same rate, the index is not moved. One pendulum has a magnet as a bob, and this is acted on by a coil carrying the main current, so that the accelerating force of gravity is assisted. This clock then goes faster when lamps are on. This meter is not capable of the highest theoretical accuracy, because the frequency of a pendulum varies as the square root of the accelerating force, not as the accelerating force. To keep down the error arising from this, it is necessary to allow the current to modify the frequency by a very small percentage. A limit is soon reached, however, for this percentage cannot be reduced beyond a certain value, or inaccuracy in timing the clocks will cause serious errors. It must be remembered that any want of regulation of the clocks causes an error which goes on accumulating day and night, or even while the consumers are out of town. As an example, suppose a house wired for one hundred lamps, and suppose the meter calibrated to read accurately at small loads. Let the maximum number of lights often used at a time to be fifty, and suppose the meter arranged so that fifty lights alter the frequency of one clock 5 per cent. The error due to the square root law is then 2 per cent., so that the meter reads 2 per cent. wrong. Suppose the average load is equal to five lamps always on, the current has the effect of altering the speed of one pendulum ½ per cent. on an average. In order that the error due to want of regulation of the two clocks need not be more than 2 per cent., they must keep time with each other within 100th per cent., that is to say, they must keep together within one minute in a week. It is difficult to make clocks as good as this, but the makers of the Aron meter seem to have succeeded. It would be better to act on both pendulums, quickening one and slowing the other ; the error could then be reduced to one-half. Attention is called to this error, because it is as well that it should be understood. Such a meter as the Aron is probably more accurate than any of the meters which involve compromises between first and second power laws.

The next class of meter is very large. A meter may consist of an amperemeter or wattmeter and a clock. The clock moves the index-train every half minute or so, and the movement is regulated by the amperemeter or wattmeter. For instance, the amperemeter may carry a snail, like that used in the striking mechanism of clocks. In a clock, the tumbler falls every hour, and the number the clock strikes is regulated by the position of the snail carried by the hour-wheel. Similarly, in the meter, the tumbler or feeler moves every minute or half-minute, and its stroke, and therefore the movement of the index, depends on the amperemeter. The various mechanical arrangements for doing this are numerous ; but, as they are all the same in principle, it is not necessary to describe the different snail meters. The chief difficulty occurs with small loads. For instance, if a meter is to read from one to one hundred lamps, the feeler must move the train even when it has only 1 per cent. of its full travel. The stroke of the feeler at no load again must be too small to move the index mechanism. If this is driven by a ratchet, for instance, the movement must be less than one tooth. It is then difficult to arrange the feeler so as to be perfectly clear of the snail ; and if it does not clear the snail at no load, it may hold it and prevent registration when a load comes on. Some designers use clocks driven by springs, and others employ electrical clocks which require no winding.

Meters of this class have been designed

by the Brush Co., Messrs. Brillié, Cauderay, Frazer, Hartmann and Braun, Siemens, Lord Kelvin, and many others. They can be easily arranged to work with continuous or alternating currents, and can be arranged as coulombmeters or joulemeters.

There have been many attempts to produce heat-engine meters. This form labors under great disadvantages as to starting at light loads, for the power available is then extremely small, and many of these meters may be regarded as heat-engines which work through small ranges of temperatures at small loads, so that the efficiency is also exceedingly small. Professor Forbes has produced the most successful heat-engine meter. It consists of a resistance which heats when there is a current, and causes convection currents in the air. These work a small horizontal windmill, and this works the train. The power spent in the resistance varies as the square of the current, so the rise of its temperature varies as the square too if the air passing varies as the current, and the rise of the temperature of the air also varies as the current. The air will then carry off the heat at a rate proportional to the square of its speed, that is to say, at the rate it is generated. The efficiency of a heat-engine depending on small changes of temperature varies as the difference of temperature, so that the power available to expand and thus move the air varies as the cube of the current. If the air resistance varies as the square of its speed, as it is supposed to when the movement is quick enough to make vortices, the Forbes meter obeys theory accurately. It would be interesting to know what Professor Forbes has to say to this explanation, for he found the meter was very accurate, but that, according to theory, it should have been inaccurate. The energy taken to work the windmill is a very small portion of the work done by the meter. The chief difficulty is to make it start with small loads. For instance, suppose the meter has a drop of ½ volt with 100 amperes, it then has 50 watts. With 1 ampere it has only 0·005 watt, and it is exceedingly difficult to make a windmill that will be moved by the draught caused by $\frac{1}{200}$ watt. The meter is, however, a wonderful piece of work, the windmill rotating almost without perceptible friction, and being beautifully light.

There is still one form of meter to be mentioned, and that consists simply of a clock which goes only when the consumer uses power. The consumer is then charged so much per hour for the light. This kind of meter has not any chance of wide application in this country ; but Mr. Aubert's meter, which is on this principle, has had enormous sales on the Continent.

A discussion of the various uses of instruments, or practical electrical testing, would occupy too much time ; so descriptions of the various methods of testing dynamo machines as to efficiency and durability, of taking the efficiencies and characteristic curves of transformers, incandescent and arc lamps, and secondary batteries, have to be omitted. To do justice to this part of the subject it would require a separate Paper.

Mr. **James Swinburne** added that among the instruments described in the Paper as of the Schuckert type, he ought perhaps to have mentioned one made by Messrs. Crompton, which was a modification of that type. When he wrote the Paper he knew the instrument, but did not know that it was sold so largely. He also wanted to mention a matter of history with regard to the wattmeter. It had been referred to in the Paper as if it had simply grown; but it was really invented, and it was only fair to call attention to it, as another of Professors Ayrton and Perry's numerous inventions. He had mentioned the ohmmeter as being introduced to the Institution by Lord Kelvin; but, on looking the matter up, he was not quite sure who was the inventor. From an early patent of his, in 1858, it appeared that Lord Kelvin had an instrument with a wire field; but he could not say whether it was used as an ohmmeter, or simply as a galvanometer with definite needle control. At any rate, in 1880, it was introduced as a commercial instrument for measuring resistances.

Professor W. E. **Ayrton** said it had been stated quite correctly that "a station supplying at 100 volts does not require its voltmeters to read from 10 to 150 volts, but should be provided with instruments whose whole scale is devoted to readings between, say, 97 and 103 volts, if there are no feeders." Professor Perry and he were then derided for having "devoted unlimited ingenuity to making instruments with equally-divided scales." He did not think, however, that the author had quite grasped the fact that the very result at which he aimed—that of getting an instrument which should read over the whole scale from 97 to, say, 103 volts—could be fulfilled by an instrument which had an equally-divided scale. Among the instruments on view in the library, there was one dated 1882, which had a circular scale, comprising nearly 360°, which was equally divided, the pointer going through equal divisions for equal additions of current, and also fulfilled the very aim that the Author had in view, going from one end of the scale to the other for an addition of, say, 5 or 6 volts. This was perhaps the earliest example of the type illustrated in *Figs.* 1 and 2 of the Paper. It had a soft iron needle, and the result in question was obtained by opposing the motion of the needle by a spring, and giving the latter a set, by means of a movable hand; so that the needle could start moving from zero for, say, 97 volts, and deflect over the whole circumference for an addition of 5 or 6 volts. The set could be arranged at will, and any 5 or 6 volts in the range could be selected, the pointer going through four right-angles for something like the same addition to the P. D. The instrument had two springs, one or both of which could be employed in controlling the needle; so that not only could the 5 or 6 volts required to move the needle through 300° be selected—for example, 20 to 26 volts, 50 to 56 volts, etc.—but the number of volts causing the needle to move through 300° could also be varied by using one or both springs. He mentioned the matter, because it would appear from the Paper that an instrument with an equally-divided scale could not be used for a central-station voltmeter to indicate between 97 and 103 volts.

The question of the material for springs was one to which he had devoted much attention. If steel could not be used—as was often the case, for magnetic reasons—the material which had the least sub-permanent set, he had found to be, not German silver, as was often supposed, but phosphor-bronze. There was a special kind of phosphor-bronze, which Professor Perry and he originally obtained from France, that had a very small amount of sub-permanent set. He had tried platinum and various alloys of iridium, platinoid, and other alloys, but undoubtedly the best was phosphor-bronze. The Author had referred to the difference in the extent to which various instruments were shielded from external magnetic disturbances. That was a consideration which had great weight with Professor Perry and himself, when bringing out the magnifying-spring instrument in 1882-3. If they wanted an instrument to be unaffected by external magnetic disturbances, it should have a motion of translation, and not a motion of rotation. It was a well-known principle that a uniform field, no matter how strong, would not cause a magnet to move bodily. Magnetic needles could be floated on corks in water, and they would all turn to the north, but they would not travel across the vessel in which they were floating.

The Author had referred to the "twisted strip" in the Ayrton and Perry instrument. That name, however, had been improperly applied by the Author, and belonged to another and more recent arrangement, not referred to in the Paper; the instrument illustrated and described in the Paper was one with a "magnifying spring," a kind of spring whose free end rotated through a large angle for a small axial extension. The "twisted strip" was a later device: When a current was sent through the strip, it was slightly warmed, and the warming caused a great alteration in the amount of twist; so that a small current passing through the strip caused the pointer to rotate through a large angle.

There was one point on which they were liable to be misled; viz., with regard to electrostatic voltmeters not being affected by an external field. At first sight this appeared to be right; and he was a little astonished to find one reading wrongly when near a transformer. An electrostatic voltmeter, unless precautions were taken, was comparatively easily affected by currents set up in the stationary and moving parts, due to a rapidly varying field. If the instrument were put near the transformer, it might be many volts wrong, due to the current induced in the stationary and moving parts of the metal by the rapidly alternating stray field in the transformer. The Author had referred to the split dynamometer, and had said, "On the other hand, the same instrument, arranged so as to have greater errors, and called a split dynamometer, has till lately been treated as accurate." He might mention that there was one way of using a split dynamometer shown in a Paper by Dr. Sumpner and himself, read at the Physical Society,[1] which was absolutely correct. There might be any amount of self-induction or mutual induction, or any amount of stray field in the transformer, but that particular method of using the split dynamometer was absolutely correct. It was only right to make that statement in defence of Mr. Blakesley, the inventor of the arrangement. And it was very important to bear in mind that the accuracy of the method alluded to arose from there being no self-induction to be compensated for; and not because a large non-inductive resistance was used to swamp the effect of self-induction—the condition aimed at in a wattmeter. The Author had mentioned 5 per cent. as the change in light corresponding with 1 per cent. change in pressure. He thought that this was, indeed, rather a low estimate, and that it was nearer 7 than 5 per cent.

The Author, from a feeling of modesty,

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[1] Proc. Physical Soc., vol. xi. part II. p. 176.

had not laid sufficient stress on the novelty of his own invention—his own meter. It was an entirely new form of supply-meter, based on the use of a motor with a constant load, as distinct from one with a varying load. Hitherto, all supply-meters using motors had used them with varying load, or resistance proportional to the velocity, or something of that kind; but the Author's meter was totally different: it was a meter in which the resistance was constant, requiring therefore only a constant current to drive it, and going at a speed which was proportional to the difference of potentials at its terminals and to the current passing through the house. It was an entirely new principle, and a very promising one.

He (Professor Ayrton) had taken up the electrostatic volmeter latterly, in conjunction with his assistant, Mr. Mather. If they could only get a good one it was far superior to any other. In the first place the great waste in power was annihilated. The most expensive voltmeters in working were the hot-wire ones. The Author had pointed out that each watt represented interest on £1 at 7 per cent. A hot-wire voltmeter of a well-known type, reading to 100 volts, required 35 watts, and when reading to 200 volts, 70 watts ; so that it was a question of interest on £70 at 7 per cent. It only cost about £8 to buy the instrument, but, in power wasted, it was equivalent to an investment of £70. An electrostatic voltmeter, as was well known, could be used for alternating currents as well as for continuous currents. The first point to be considered was the shape of the needle. Most people used a flat needle, following Lord Kelvin in his quadrant electrometer, and the author used a flat needle in his electrostatic voltmeter (*Fig.* 25). He did not think that a flat needle was the right thing, because it was not nearly as stiff as a cylindrical needle, and, therefore, the stationary parts could not be put as near the moving parts as in the case of a cylindrical needle. They could not, therefore, make a flat needle as small as a cylindrical one, and obtain the same amount of electrostatic twist; hence the periodic time could not be as small, or the instru- as dead-beat, with a flat, as with a cylindrical, needle. By using the latter form, greater sensibility could be secured, and also considerable dead-beatness and cheapness. But, when dealing with alternate-current instruments, it was necessary to have very good contact between the moving needle and the stationary parts. And, as a cylinder would be built up with spokes, and there were two sides to the cylinder, they had found considerable difficulty in getting good contact with rapidly-alternating currents; they had therefore devised a special form of needle, into the details of which he would not enter.

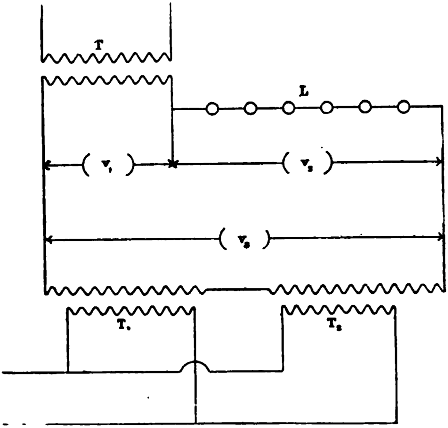
There were several electrostatic voltmeters, constructed by Mr. Mather and himself, exhibited for the first time. They showed a large range and angular motion —larger than was obtained in Lord Kelvin's instrument; there was also greater sensibility and dead-beatness. One of the instruments had only a single needle, but it would easily measure down to 40 or 50 volts, and that without any magnification whatever, and it was fairly dead-beat. The result was obtained, first, by using a cylinder, not a flat needle ; secondly, by bringing the moving and the stationary parts very near together, which could be done with a cylinder, but not with a flat needle ; and, lastly, by making the stationary and moving parts of such shapes as to give a very open and equally-divided, scale. Some instruments exhibited by him had a spring control, others a torsional control, and others a gravity control. The spring control was very convenient, because the instrument could be used in any position, and the reading could be taken with equal accuracy.

Dr. J. A. **Fleming** said that he had been working a good deal with electrostatic voltmeters of the Author's construction, and could, therefore, add something on the theory and uses of that instrument, to the discussion. He wished to echo Professor Ayrton's remark as to the desirability of using electrostatic voltmeters in central stations as far as possible, on account of the great waste of power involved in using any form of electro-dynamic voltmeter. The worst had not been said about the hot-wire or electro-magnetic instruments. Not only did the voltmeter itself consume a certain amount of power, but there were other sources of loss. In the Cardew voltmeter, for instance, the loss of power was from 30 to 35 watts, when working on an ordinary 100-volt circuit ; but when such voltmeters were used on alternate-current circuits working at 2,000 or 2,400 volts, it was necessary to associate with them a step-down transformer, in order to reduce the pressure to about 100 volts, to bring it within the range of the voltmeter ; they must therefore credit the voltmeter with all the loss incurred by the use of the transformer, which was not a light matter. An ordinary Cardew voltmeter working at 100 volts, and absorbing 30 watts of power, represented, if the voltmeter were kept on continuously, three-quarters of a unit of power lost per day in the voltmeter ; and to that should be added the loss in the transformer, which might be two or three times as much. In replacing these instruments by electrostatic voltmeters, there were some difficulties that he had not yet seen overcome in any instrument in the market. One was that electrostatic instruments generally had scales extending over a comparatively narrow range. Lord Kelvin's beautiful instrument, the multicellular electrostatic voltmeter, measured only from 60 to 120 volts, and the divisions on the scale were by no means uniform, but were widest at a certain point in the scale, and diminished in both directions ; therefore the same accuracy of reading was not obtainable in all parts of the scale. Then there was the objection that, with high tensions, it was impossible to bring the moving system very near to the stationary part of the voltmeter, without incurring the danger of sparking across. Of course, an electrostatic voltmeter of the kind described in the Paper was nothing more or less than a condenser, one plate of which was movable; and the two plates could not be brought nearer than a certain limit without incurring the danger of a discharge from the needle to them. That limited the sensibility of such instruments. The Author had lately lent him some electrostatic voltmeters for experiments in measuring the power taken up in the cores of transformers. They were intended to be used for 1,200 volts, but they had been pressed up to 3,000 or 4,000 volts, which was rather unfair treatment. The general course of events was that, when the observer had taken a couple of hours to calibrate the instrument, and had got it to work, a discharge passed across, burned part of the needle, and destroyed the suspension. They had, however, overcome that easily, by sandwiching the needle between two plates of mica, which extended a little over on both sides. The same result might be attained by lining the inside of the quadrants with mica. It was not found that this change introduced any difficulty, and it obviated the risk of the destruction of the interior of the voltmeter by a discharge passing from the needle to the quadrants. The question of measuring alternate-current power was a most important matter, and Dr. Fleming did not think that it had yet been satisfactorily solved.

Many methods had been projected and described for measuring power taken up in an inductive circuit—a circuit consisting, say, of a large number of transformers on open secondary circuit; some of them were known to be very inaccurate, and others accurate in theory, but with many practical objections, such as being inconvenient or incapable of being applied in practice in a central station. One of these, the so-called 3-voltmeter method, was suggested simultaneously by the Author, Professor Ayrton and Mr. Sumpner. Theoretically, it was a perfect method; but it had the great objection that, in practice, it was necessary to have available double the working pressure. If it were required to measure the power taken up in the primary circuit in a transformer, a non-inductive resistance had to be made, of which the ohmic resistance should be approximately equal to the impedance of the primary circuit. Suppose this resistance to consist of a series of incandescent lamps, which formed a good practical non-inductive resistance; then they had to provide the means of producing twice the working pressure of the transformer. Suppose the transformer to be working at 2,000 volts in the primary circuit, they had to provide a total pressure of about 4,000 volts. Of course, the easiest way was to join up the two other transformers with their secondary circuits in series, and their primary circuits in parallel, and so to build up 4,000 volts. Then the three voltmeters had to joined, as shown in *Fig.* 26, and the simultaneous readings taken; the result being to give, by means of a simple formula, the power taken up in the primary transformer. That method was theoretically correct, but difficulties presented themselves in practice.

In the reduction of the observations, they had to take the difference of the squares of the voltmeter readings. A small error, say 1 per cent. in the reading of one instrument, would mean an error of 2 per cent. in the value of the square ; and, if the errors in two readings lay in opposite directions, there might be an error of 4 per cent. introduced, even under the most favorable conditions, by an error of 1 per cent. in the voltmeter readings. Suppose it were desired to measure power coming from an alternate-current station, it could not be done by this method, because it would be impossible to provide the necessary excess of pressure. It had, therefore, been suggested to use a method which employed three amperemeters instead of three voltmeters. He had recently found it possible to reduce the number of instruments to one ammeter. The difficulty encountered was the same as in the other case, that they had to take two observations and square the readings, and take the difference of the squares ; and the results, owing to errors of reading, were sometimes very disappointing, even when they took pains in the measurements. He was at present scheming an arrangement for taking the two current-readings simultaneously by a differential dynamometer of some kind ; so as to read the difference of the squares of the current directly, without the necessity for making two separate observations with the same instrument. But methods of measuring inductive power had yet to be perfected. He could not share the view taken by the Author of the dynamometer-wattmeter, as a means of measuring power with highly inductive circuits. The general theory of the instrument was well known, and it was well known that the instrument, if calibrated by constant currents, would not give correct readings of power on an inductive circuit, unless certain corrections were made in the readings. It had been generally supposed that an ordinary wattmeter, of which the fine wire circuit consisted chiefly of non-inductive resistance, put outside the instrument, could be used for measuring power on inductive circuits; and it was known that under ordinary circumstances the reading of the wattmeter would be too large. As far as he had gone in experiments with a wattmeter of that type, comparing it with measurements by

Fig. 26.



3-Voltmeter Method of Measuring Inductive Power.

T, Transformer under test; L. Non-inductive resistance; T_1, T_2, Transformers supplying double pressure; V_1, V_2, V_3, Electrostatic voltmeters.

the three-voltmeter method, the wattmeter very often measured too little. He had not been able to fully ascertain the reason, the researches being still in progress. He did not think that they could invariably trust to the dynamometer-wattmeter, as a means of measuring inductive power. A great deal has yet to be done in discovering the causes of error in such instruments.

With regard to the subject of house-meters for alternate-current supply from central stations, there was much to be said. It was essential to ascertain that a wattmeter, or a house-meter of any kind, to be used in measuring alternate current supply, should be one which was not affected by a stray magnetic field. There were many types of meter which, if they were put near a transformer, especially an open circuit one, would run round without any current going through them, and could be even arranged so as to go in the wrong direction and entirely vitiate the reading. It was essential to ascertain, by direct and careful experiments, whether a house-meter, in which there were a disk of metal (copper or iron), was affected in the way he had described when it was placed near a transformer with an open or closed circuit; because, if there was much stray field from the transformer, it might cause the disk to revolve in a right or a wrong direction, and the result would be disastrous, either to the customer or to the central-station supply.

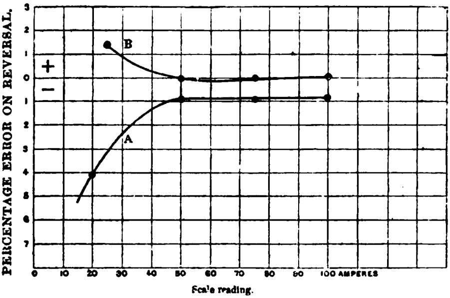
Mr. A. **Siemens** said a few words in defence of the electro-dynamometer. The Author had spoken as if it were only in use on alternate-current circuits, but he (Mr. Siemens) believed that it was much used as a standard instrument, by which to correct more modern inventions, and to give them their proper bearing when they got out of order, which they were very liable to do, but which the electro-dynamometer was not. He believed it was Sir William Siemens who first suggested the wattmeter. It was one of Weber's electro-dynamometers, with one coil for the volt-circuit and one coil for the ampere-circuit.

Mr. **Sidney Evershed** said that the

Author had done good service in drawing attention to the real requirements in electric house-meters. He had laid down certain conditions that all indicating measuring instruments should fulfil. "For years," he said, "designers have been devoting unlimited ingenuity to making instruments with equally-divided scales." Such designers, however, he thought, existed only in the Author's imagination. All the well-known instrument makers had, during the last five or six years, calibrated every instrument they had made, without assuming that it obeyed any simple law at all. The Author had laid down the conditions with regard to variation by temperature, and absence of errors from hysteresis, and stated that those requirements had nearly all been fulfilled by leading instrument makers. Mr. Evershed did not know whether he ought to pose as a leading instrument maker; but he would say that some of the requirements in perfect electric measuring instruments, were far from being fulfilled at the present time. Considerable progress had been made during the last five years in eliminating the error due to hysteresis, which used to be enormous in many measuring instruments; but they were still far from perfect. In many instruments of the Schuckert pattern, his own included, that was to say, instruments in which small pieces of iron were magnetized by a coil, and the attraction of one or more of them measured—the hysteresis error did not depend in the least on the design of the instrument, but only on the length of the iron magnetized in proportion to the total magnetizing force of the coil. At high readings, anywhere near the top of the scale, errors were, as the Author had said, almost negligible; but at low readings, say, to 10 amperes in a 100-ampere instrument, serious errors were sometimes introduced. He had, during the last year, attempted to solve that apparently impossible problem of either getting the iron absolutely free from hysteresis, or compensating the instrument for the hysteresis error, and he exhibited the diagram, Fig.

27, showing how far he had gone. He admitted that it was not entirely satisfactory, but it was a step in the right direction. The lower curve represented the percentage error when the connections of an ordinary instrument were reversed, so as to send the current in the direction opposite to that in which it was previously going. It would be seen that, at about 10 amperes, the error was already 6 per cent. The upper curve represented similar observations taken with an instrument which was compensated for hysteresis. The error, it would be observed, was reduced from 6 per cent. to 1.5 per cent., and in the upper end of the range the error was practically eliminated; at least, they could not detect any. The method of attaining that result was very simple. If he diverted part of the induction passing through the fixed pieces of iron (*Fig.* 7), through a piece of iron or steel—anything which had a larger hysteresis effect than soft iron, he could so arrange matters that the induction passing through the rod by which he measured the current was constant. The only other serious error in a voltmeter was that due to temperature. He showed a curve from two voltmeters made by Messrs. Goolden (*Fig.* 28). The ordinary instrument, when put into circuit, fell in the reading, owing, of course, to the heating and the consequent rise in resistance. The lower curve showed the effect, and gave readings up to ninety minutes after putting the instrument into

Fig. 27.



Difference in Ammeter Readings on Reversal of Current in Coil.

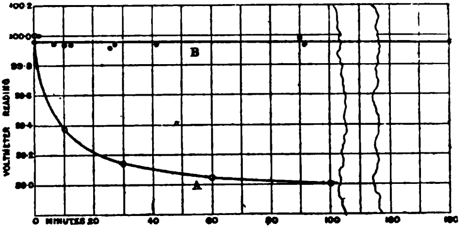
A, Ordinary ammeter showing effect due to hysteresis of iron core; B, Ammeter compensated for hysteresis effect.

circuit. The total fall was 1 per cent. With the compensated instrument, he had drawn a straight line between the first observation, taken at the instant of putting into circuit, and the last, taken after the voltmeter had been in circuit for three hours. It would be seen from the diagram that all the intermediate observation fell on that line, within less than one-tenth per cent.; that is to say, within the amount of observational errors. In other words, there was absolutely no difference in the reading of the instrument, although its temperature had risen 30° Centigrade. He thought that the descriptions in the Paper of some of the instruments were rather meagre, and in one or two cases there were slight inaccuracies. The Author had described two instruments (*Figs.* 7 and 8), one as an Evershed and the other as a Hartmann-and-Braun instrument. It would have been more correct had both been described as Evershed instruments.

The Author had alluded to Lord Kelvin's lamp–counter as almost the only survivor of the tangent galvanometer.

He (Mr. Evershed) had placed on the table an ammeter which he had made at the suggestion of Professor Kennedy, for the Westminster Electric Supply Corporation, to measure the leakage on circuits. As it was much on the same lines as Lord Kelvin's, he thought it might be of interest to note its use. When the Author referred to alternate-current instruments, he possibly overlooked the fact that if there were any kind of measurement which

Fig. 28.



Time after application of 100 volts.

Variation of Readings on Voltmeters due to Rise of Temperature.

A, Ordinary Evershed voltmeter; B, Ordinary Evershed voltmeter compensated for temperature.

could be made by an instrument containing iron, it was the measurement of alternate-currents and alternating pressures, for the simple reason that the hysteresis error was entirely absent. He had mentioned that Mr. Evershed and he had proposed to use condensers. The Author had no doubt proposed that method, but Mr. Evershed had used it during the last two years with great success. The method was very simple, and he could not imagine why it had not been more generally employed. A voltmeter, compensated by a condenser, would read absolutely the same with both alternating and continuous currents.

With regard to meters, the difficulty in making an electric house-meter was solely one of power. They were so accustomed to measure gas and water by meter, and to have practically no restrictions with regard to the power employed, that they were apt to lose sight of the fact that the whole difficulty in measuring electricity was due to the circumstance that they could not afford to lose any volts in the meter, while the current was on its way to the house ; nor could they waste more than a-tenth of an ampere, at most, in a shunt across the mains. There were very few meters in the market which would stand such rough usage as a gas, or water-meter. He had occasion, a few months ago, to see a water meter tested, in the case of a disputed account. The meter had been put in a pit, frozen several times, and subjected to most severe treatment, from an electrician's point of view ; yet, when tested, it indicated correctly within 2 per cent., and that was after six years' use. He did not think there was any electric meter which would last six months under those conditions ; and, until they could get a meter which would last, not six months, but six years, he did not think inventors could claim to have made any great advance towards perfection in the electric-supply-meters.

Mr. Gisbert Kapp said he would like to correct the drawing in *Fig.* 15, representing an instrument designed about nine years ago by Mr. Crompton and himself. The drawing was one of the first type, but it was not a satisfactory instrument. The coil C was not set at right-angles to the line joining the poles of the electro-magnet, but at an acute angle ; and by that means they were able to obtain a scale of about 90° opening—in fact, a very readable scale. He mentioned the matter, because, if any one tried to make an instrument like that in *Fig.* 15, he would not find it satisfactory ; he must swivel the coil first.

In dealing with the question of indicating instruments, it was impossible to cover the whole ground in so short a paper. The Author had left out one consideration which was of some practical importance, that of getting a current-indicator or ammeter which should not swing too much. He had taken great trouble to obtain an ammeter for gas-engines, and all the English makers to whom he applied had said that they could not produce a properly damped instrument, the needle of which would stand practically still whilst the impulses from the engine came and went. He had met with no success until he applied to Mr. Evershed, who had put on a damping arrangement that was so simple, ingenious and effective, that he would describe it. The damping arrangement consisted of a light rectangular piece of iron wire, which was pivoted on fine points, and hung just in front of the needle. If the current-impulse came, the iron was drawn up against the needle, and so created momentarily sufficient friction to prevent the needle from swinging out too far. It was a very simple arrangement, costing only a few shillings, and members would be glad to know, that, if they were troubled with ammeters which swung too much to give accurate readings, they could correct them by that contrivance. The Author had laid great stress on the necessity of supply-meters being absolutely reliable, especially as a meter which was made for forty or fifty lights, was generally worked with a much smaller number —ten or fifteen—and, having a small current passing through it, the power available for working it was very small. If the meter were of the pendulum type, first introduced by Professors Ayrton and Perry, it might register backwards when no current was passing. That had happened in his own case. He had a meter in his office, which, during the last few weeks, while he had not used the light, had actually registered backwards; so that the Company would have to pay him, instead of his paying them. The inspector had been several times to see it, and had at length set it right. The meter was perfectly set; he had checked the two pendulums for days together, and they swung absolutely in unison; but, after six months, it was found that they had to be re-set. In that respect, a meter of the motor type was far preferable, because it could never go unless the current passed through it. It was possible that it might not go if a small current passed through it; but it would never register either forwards or backwards when no current was used. A meter of that kind would never be unfair to the person supplied. It might be unfair to to the Companies, but it was to their interest to keep meters right. On the whole, therefore, he preferred the motor meter to the pendulum meter.

Mr. R. E. B. CROMPTON supplemented the Paper, by giving a short description of the method of electrical testing employed by his own firm, in common with others, for obtaining accurate electrical measurements—such as those necessary for obtaining the efficiencies of electrical machinery, dynamos, motors and the like ; and also in actually standardizing the instruments they manufactured and sold. They commenced by using several of the forms of commercial instruments that were in the market, but soon found that, although such instruments were extremely accurate under certain conditions, they were not sufficiently accurate under the conditions in which they had to be used in engineering works, or at central-stations for the supply of electricity. In both cases, the readings of many of the best instruments were liable to be disturbed by the stray magnetic fields of varying strength, which were always met with in such workshops ; and it was necessary to have a standard form of apparatus free from this defect, which could be thoroughly relied upon. It was principally owing to Dr. Fleming that he began what had been called the potentiometer method of measurement. The arrangement is shown diagrammatically in *Figs.* 29 and 30. The potentiometer itself consisted of a wire AB stretched over a frame. The wire was made of an alloy of platinum and iridium, and was extremely hard. Great pains had been taken to ensure that it was accurately drawn, and the alloy well mixed, so that the electrical resistance per unit of length was very constant. It was a mechanical engineer's job, after the wire had been put in position on the instrument, to calibrate it. It was much the same thing as scraping up a surface-plate. The parts where the resistance was lowest had to be brought up to the standard; by slightly reducing the gauge at those points by rubbing, the whole wire was brought to an extremely high degree of accuracy.

The following was the way in which the instrument was used. It was supplied with a constant current by means of a small secondary battery consisting of three cells in series; in this circuit there was also a variable resistance, which was made so that it could be readily adjusted to reduce the electromotive force of the three cells so as to give a difference of potential of 4 volts at the ends of the wire. C was a contact-slider connected with a wire from the galvanometer, and having a knife-edge to make contact on the wire A B at any desired point in its length. The galvanometer was preferably a sensitive one of the Deprez—d'Arsonval dead-beat type, with a multiple switch, so arranged that the numbers of pairs of contacts on it corresponded with the number of electromotive forces X, Y, Z, &c., required to be measured. One of these electromotive forces should be the standard with which it was desired to compare the unknown electromotive force.

Fig. 29.

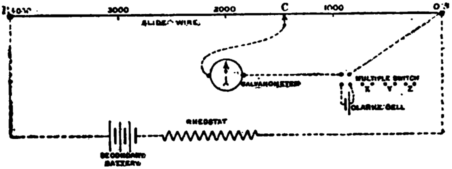
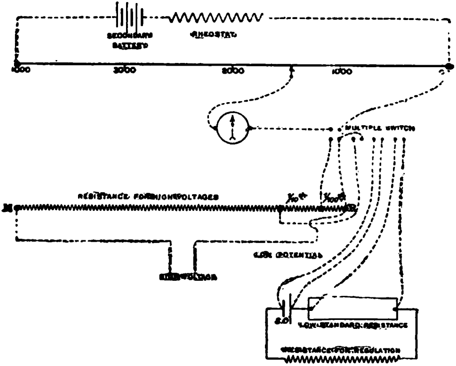


Fig. 30.



Method of Taking High Voltage Readings; also of Measuring Currents and Low Voltages.

The standard generally used for this purpose was the well-known Clark cell, which was considered to give a definite electromotive force of 1·4380 legal volts at 50° Centigrade. As the electromotive force of these standard Clark cells varied with the temperature, it was usual to mount them in a stand provided with a thermometer which indicated the actual temperature of the cell itself. A table was attached, showing the electromotive force of the cells to five places of decimals, for each degree of temperature. In order to measure electromotive forces up to 4 volts, the contact C was first placed at a point on the scale corresponding with the temperature value of the Clark cell at the time the measurement was made. For instance, if the temperature were 15° Centigrade, the corresponding value of the Clark cell being 1·4380, the contact was placed at 1,438 scale divisions measured from the point A. The standard Clark cell *s c* must then be switched in by the multiple switch, and the variable resistsistance adjusted, until no current passed through G when the contact C was pressed down. This was called balancing the Clark cell. It meant that the electromotive force at the point C, or the potential difference between A and C, was exactly 1·438 volts, corresponding with 1,438 scale divisions ; therefore each scale division was $\frac{1}{1000}$ volt, and division 4,000, at the terminal of the wire, was exactly 4 volts. To measure any desired electromotive force, X or Y, those must be switched in so as to take the place of the standard cell. The slider was then moved until the galvanometer again came down to zero, showing that no current was passing through it. The reading taken at the contact point C, in scale divisions, was the actual reading in volts. When measuring from 1 to 4 volts, it was necessary to put the decimal point three places to the left. For instance, if the reading were 2,020, it would represent 2·02 volts. For measuring electromotive forces greater than 4 volts, a multiple resistance M R, of about 5,000 ohms, was used. This had intermediate contacts, so arranged that the potential difference could be measured at any desired decimal fraction of the total potential difference between the extreme terminals of that resistance. It was generally found sufficient to take such fractions as $\frac{1}{1000}$, $\frac{1}{100}$, and $\frac{1}{10}$. As a potential difference up to 4 volts could be measured on the potentiometer itself, if this were taken over $\frac{1}{1000}$ of the total, it was evident that the total potential difference at the terminals of MR must be multiplied by this figure —that was, that 4,000 volts could be measured. For measuring currents, the potential difference was taken at the terminals of resistance, which were generally either 1 ohm, $\frac{1}{10}$th ohm, $\frac{1}{100}$th ohm, and $\frac{1}{1000}$th ohm, etc. Up to 4 amperes, the ohm was used; up to 40 amperes, the 10th; up to 400, the 100th, etc. In this case, also, the readings of the instrument were taken directly from the scale divisions, the position of the decimal point being moved to the right as each lower fraction of the ohm was used. When very strong currents were measured by taking the potential difference at the terminals at low resistances, it was of great importance that the fractions or sub-multiples of the ohm used, should be so contrived as to be not heated by the current passing through them. The matter had lately been expressly urged upon his notice. It was found that, in order to get great accuracy with air-cooled resistances, the apparatus became bulky, and even then the temperature errors were serious. He had contrived a method of enameling, to protect the resistances from the action of water, and cooled them by water-circulation round them. In that way he had contrived resistances of very moderate size, which could be kept at a constant temperature, even though large currents were passing through them. The accuracy of measurement obtained in that way was surprising. It was possible to compare differences of potential to within 1 part in 4,000. The instrument could also be used for making almost any kind of comparison where continuous currents were used. It had the special merit that it could be taken abroad to any part of the earth, and it could be repaired *in situ*. There was no delicate part about it, and; if the calibrated wire were destroyed, it was possible for the operator himself to make a new one. All that was necessary was to rub or scrape the wire so that the resistance per unit of length was equal from end to end, and that could be tested and adjusted on the instrument. In that respect it differed from all the other forms of apparatus which depended upon delicate adjustments; and which, after having been damaged in transit or in other ways, had invariably to be sent back for re-adjustment and re-calibration. The only re-calibration required in the instrument he had described, was after the replacing of the wire; all the rest of the instrument was fixed. It had no moving parts, pivots or delicate springs to be corroded or damaged, such as there were in all the other forms of instruments that he knew.

LORD KELVIN was sorry not to have

been present when the Paper was read, but had read with great pleasure a copy of it kindly sent by the secretary. It was, of course, impossible to present a thorough treatment of the subject in so short a paper, but as a record, or an index, of what had been done it was very comprehensive. The various principles that had been adopted for electrical measuring instruments had been touched upon in a fair and appreciative spirit. The Author had remarked, with reference to his (Lord Kelvin's) multi-cellular electrostatic voltmeter: "This instrument has a horizontal dial, but it is provided with a mirror, so that the readings are visible in front, if it is on the level of the eyes." Although by this method readings could be taken with fair convenience, he felt that especially for a central station of electric lighting, it would be an improvement if the mirror could be done away with, and the instrument made to show at once on a vertical scale. He had therefore introduced a modification, which had only been finally tested in his laboratory a few weeks ago. It gave its readings on a vertical cylindric scale, which could be read at distances of many yards. There was another point against the electrostatic voltmeter, which the Author had not mentioned, but which he thought was of some importance—the provision of some automatic checking arrangement, so that the instrument would be practically dead-beat. He had found that that could be done in the simplest manner by a well-known expedient, corresponding to the dash-pot in engineering. Without disturbing the general structure of the instrument, he could readily hang a vane on to the lower end of the stem that carried the needles; and that vane working under oil, was so arranged that it produced a practically dead-beat instrument. The Author's remarks upon the subject of the measurement of electric activity were very important, and ought to be taken to heart. There was a general impression that a wattmeter for alternate currents was impracticable without a certain complication of scientific adjustment which the Author had described. The Author, Professor Ayrton, Mr. Sumpner, and Dr. Fleming had gone into the subject in a very thorough manner, and had brought out scientific developments of remarkable and interesting character. He nevertheless heartily concurred with the Author's remark—"It is, however, useless to employ complicated methods of measuring power when a simple one is better. The prejudice against the ordinary wattmeter has no real foundation." Let the fine wire coil of the ordinary wattmeter have a sufficient anti-inductive resistance in its circuit, to produce the result that the current through the fine wire coil should be, nearly enough for practical purposes, the same as it would be were there no inductive impedance, and were there no effect of inductive action from the fixed coil upon the movable coil: these conditions being fulfilled, the wattmeter's measurement of activity was correct. The Author had rightly remarked that, "if any one will take a real instrument, designed with a little care, and substitute the approximate values of R and L, he will find that he has been straining at a gnat." He might have added, "and swallowing a camel," taking into account the very difficult methods adopted to avoid the inconveniences arising from the action of that gnat. The fact was that, with a judiciously-arranged wattmeter, there was no difficulty whatever in rendering the error due to the quasi inertia of the electric current, when the wattmeter was applied to an alternate current, practically insensible. They had always the means of testing whether it was or was not insensible and of ascertaining its value in the latter case. There was one difficulty which the Author had not thoroughly dealt with, although he was quite aware of it, This was, however, perhaps the most serious difficulty in connection with wattmeters for alternate currents—namely, the law of distribution of the electric current in the conductor. When conductors were too thick to allow the effect of their current to be calculated as if it were a current in an infinitely thin line, like a wire in an ordinary coil, then an exceedingly difficult subject for mathematical investigation came before them—the law of distribution of the current in the thickness of the conductor. He would not enter into that subject, which would require very elaborate treatment; but would merely say, that the wattmeter ought in every case to have such an arrangement of the thick conductor for carrying the main current, that the difference of distribution of the current, for different frequencies of alternation, should affect the result as little as possible. There were ways of doing that which he had discussed with the Author many years ago, and he would not then enter into the question. He had pointed out that any such arrangement was, after all, only an approximate elimination of error; the degree to which it was eliminated could always be ascertained by experiment; and at the worst, a watt-meter might require correction according to the frequency of the current for which it was used.

Mr. W. H. Preece desired to make one or two remarks from quite a different point of view, namely, from that of the user of the electric light. Engineers were in the habit of applying various processes to add to their comforts. They warmed their houses, and they took care to place thermometers in the different passages and rooms, to see if the warming apparatus behaved properly. On the other hand, most of them at present—he hoped it would not be for long—used gas for lighting; but how many of them were there who fixed pressure-gauges in convenient places in their houses, to tell them how the Gas Companies behaved, and how they maintained their proper duty? They wanted to do the same sort of thing with regard to electricity; they wanted to find out whether the electric-lighting companies, who had taken parliamentary powers to supply them with electrical energy, performed their functions and discharged their duties properly; and they could only do so, by having instruments in their houses of such a character as those described by the Author. The voltmeter which would tell them at all hours of the day the electrical pressure entering their houses, was a most convenient instrument, and it had the merit of having an economical tendency, in enabling them to see whether the undertaker was destroying their lamps or maintaining the life of those lamps. The eye was such a remarkable instrument that, while it could not detect the variation in light, it adapted itself with wonderful rapidity to change of light; and it was quite possible for any one to sit under the influence of a lamp which at one moment gave 20 candles and at another moment 10 candles, without being aware that any change had taken place, if a certain amount of time had elapsed between the two changes. The standard lamp which was generally supplied was a lamp that was said to give 16 candles with a voltage of 100. He believed that it might be reasonably accepted that a lamp supplied for 16 candles at 100 volts, would give 16 candles when new. By the regulations of the Board of Trade a certain variation of pressure was allowed on the part of the Supply Companies; but they could not know what that variation was, unless they put in their halls, or in some convenient place, a voltmeter that would tell the changes. Let them see what those changes meant. There was one law connected with the production of light by the current which was very well established, namely—within the range of the authorized variation of the voltage, the light given by a lamp varied as the sixth power of the current.

The accompanying Table gives these variations for two cases :—

TABLE.

100-Volt 16-Candle-power Lamp.		50-Volt 8-Candle-power Lamp.	
Voltage.	Candle-power.	Voltage.	Candle-power.
96	12·52	46	4·85
97	13·33	47	5·52
98	14·17	48	6·26
99	15·06	49	7·09
100	16·00	50	8·00
101	16·98	51	9·01
102	18·02	52	10·12
103	19·10	53	11·35
104	20·25	54	12·69

With 100 volts and a 16-candle lamp, it would be seen that, within a range of only 4 per cent. on each side, there was a drop in candle-power from 20 to 12 candles. That difference might go on in their houses without the eye having the least idea that such a change had taken place, owing to the remarkable power possessed by the iris, to expand and contract with the variation of light. If they could encourage the electric-lighting companies to lower the voltage without reducing the light, they would increase the life of the lamps to a remarkable extent. If, on the other hand, through any mistake, they raised the voltage to over 4 per cent. above the standard, there was a strong probability of the lamps being smashed—a thing that often happened. Those figures showed what took place when dealing with 100 volts.

There was one statement in the Paper to which he took exception. The Author had stated that the only survivor of the tangent galvanometer was to be found in Lord Kelvin's lamp-counter. If he were to cast his eyes around the world, he would find at that moment more tangent galvanometers in practical use in electrical engineering than were to be found in all the voltmeters and ammeters and all the other meters that were used in electric lighting.

Mr. JAMES SWINBURNE, in reply, said that he feared his remarks about equally-divided scales had been misunderstood. Other things being equal, an equally-divided scale might be useful ; but, unless an instrument naturally followed a straight line law, it was a mistake to try to make it do so artificially. The scale should be engraved to suit the instrument; the instrument should not be tampered with, to make it fit the scale. Referring to the question of cylindrical *versus* flat plates in electrostatic instruments, he thought it really depended upon whether they were working with low or high pressures. For low pressures, such as 100 volts, they must have the best workmanship, and get the plates as close together as possible. In that case he thought that the cylindrical form was best; but, when dealing with 2,000 volts, they were not limited by the workmanship, but by the sparking distance. That was important in connection with high-pressure instruments. At first sight it might appear easy to make an electrometer for very high pressures, because the forces were so large, but, unfortunately, the distances also were very large; so that the forces were small after all. The result was that so much was not gained on reaching high pressures. To make an instrument for 2,000 volts, was not, except as regarded workmanship, easier than to make one for low pressures. Several speakers had pointed out that he had not referred to the quality of dead-beatness in instruments. Of course dead-beatness was very important indeed. With regard to the springs, it was interesting to know that Lord Kelvin found platinum-iridium best. Mr. Siemens has referred to the Siemens dynamometer, as being an instrument commonly used as a standard to check other instruments. Lord Kelvin's balances were all dynamometers. He did not know about the Siemens dynamometers made lately, but the early instruments were certainly not accurate enough for testing, and using as standards. He had had an instrument for two or three years (it was not new) which gradually fell about ¼ per cent. per month; that was to say, the reading increased ¼ per cent. per month. The spring was steel, gilt. He did not know whether gilding injured the springs, but he thought it very likely, owing to occlusion of hydrogen by the iron. In his own experience he had found phosphor-bronze to be the best ; as Professor Ayrton had pointed out, it seemed to have no sub-permanent set. Referring to Mr. Kapp's instrument, the paper was only intended as a sort of *résumé*, and it was impossible to do more than give diagrammatic sketches, explanatory of the principles, and not the details of construction, of the various types of instrument. He did not mean to represent any actual form of Mr. Kapp's instrument. He had a great many forms, and he was one of the first to use the skew principle, to obtain a large reading. Mr. Swinburne had only illustrated the form that he thought would be the easiest to explain in a few words. He was very glad, and he thought it was very important, to have Lord Kelvin's opinion on the question of wattmeters. He certainly felt that the wattmeter had been a neglected instrument, and that it was infinitely better than the various complicated methods which were supposed to replace it. Non-inductive resistance would always swamp the inductive effect of the coil. In a well-designed wattmeter it was so small that it was not worth swamping. They need not, however, go into that subject, but he might point out that in all methods of measuring power, whether by electrostatic voltmeters, or dynamometers, or any current instrument, they had to compare a pressure and a current; and they must therefore have non-inductive resistance somewhere, and they were always limited by the accuracy of non-inductive resistance. If it were made non-inductive enough to act in one case, it would act in any other case. The inherent errors were the same, but the accidental errors, due to such methods as measuring two very large quantities and taking their difference, were infinitely greater. It might be thought that he had said little about many of the instruments. He had mentioned compatatively few of Lord Kelvin's, and had omitted some of the instruments of Professor Ayrton and Perry. But it was impossible to describe all the instruments of inventors like Lord Kelvin, seeing that they brought out a new instrument almost every week. He had, therefore, only described one or two, which he considered representative. In the discussion of various meters, he had called attention to the possibility of all index mechanism, or all metal work other than iron or nickel, being attacked by mercury, or mercury vapour. He had received a letter from Mr. Hookham, an authority on such matters, stating that the evaporation of mercury would not affect even brass index mechanism, provided that there was no contact. Contact with mercury would destroy any brass or copper work, but mercury vapor would not do so. That was very important, because it was the only objection that he could see to such meters as Professor Perry's or Mr. Ferranti's. He believed that Mr. Hookham had a new one of the same kind, and that other people were making similar instruments. Mr. Evershed had said that hysteresis did no harm in alternate-current instruments. He thought, however, that the statement in the paper was correct; namely, that an instrument which had hysteresis errors with a continuous current would be inaccurate, though not to the same extent with alternate currents. If the force were proportional to the product of the instantaneous current and the induction, and if the induction were not proportional to the current, both rising and falling, there would be an error. Lord Kelvin had pointed out to him that it would have been more accurate to have said that a correction for this should be made, as the effects can be foretold, and can be allowed for in calibrating the instrument. Mr. Kapp's proposal to use meters which registered slowly during the day was most important. There might be difficulties in designing such meters. One method that occurred to Mr. Swinburne was to use higher frequencies during the evening and during the day, and to employ meters which depended on the frequency. This arrangement would be, of course, only applicable to alternate-current systems ; and, as yet, there were no alternate-current motors in the market. But, in the future, when motors came into use, it is probable that low frequencies would be advantageous in their case, though it was a serious drawback in the case of transformers. Mr. Preece had referred to the tangent galvanometer. He could only say that if the Post Office used such a large number of tangent galvanometers, he would recommend it to alter that practice. He would mention, before concluding, that Mr. Roux had placed one of Mr. Brillié's newest meters in the Library. It was a very interesting type of joulemeter, and was the only motor meter, in commercial use, which was independent of errors arising from the variation of frictional resistance.

CORRESPONDENCE.

Professor ELIHU THOMSON desired to draw attention to a necessary correction in relation to the instrument illustrated in *Fig.* 16, which had been invented by him. The author had said "The needle A is a sort of fork of soft iron, and it tends to move round to the narrower part of the conductor, where the field is stronger." This was not quite correct. The little iron fork, or horseshoe, which was made very light, and the motion of which was opposed by a small weight carried on a radial arm extending from the axis, did not tend to move round to the narrower part of the conductor; but actually moved from the narrower to the wider part of the conductor, on account of the eccentricity of the axis or support of the needle in its relation to the single turn of conductor. The object of varying the width of the conductor in the instrument was not to concentrate the field, as suggested by the author, but in in order to render the readings on the scale more nearly proportional to the current intensities, *i. e.*, to make a proportional scale, as it had been found that a plain ring gave but slight deflections for weak currents, and gradually increased the deflections for stronger currents. By shaping the conductor so that it gradually widened in the direction of the stronger currents, a close approximation to proportionality in the readings was obtained. The advantage of the instrument was its simplicity and ease of construction, and the fact that it could be made to respond to very strong currents, whilst still maintaining fair accuracy with very moderate currents. Instruments were also in extensive use based on the same principle, but in which the conductor had several turns instead of a single turn, and in which the section of the conductor was uniform in the periphery of the coil. These instruments were largely used as indicators for both continuous and alternating currents. The same instruments, wound with finer wire and used in series with a non-inductive resistance of considerable amount, were employed as voltmeters for both continuous and alternating work. With regard to the comments made by the Author upon the motor meter manufactured by the Thomson-Houston Electric Company, one of the chief considerations which led to the development of this meter by Professor Thomson was, that it was found desirable that the meters should be applicable to both alternating and continuous currents, and that they should register the energy consumed rather than the coulombs passing. In the case of the use of alternate currents, where reactive coils were employed for modifying the delivery of energy, the meter should deduct any return of energy due to self-inductive load. This was true also of alternate-current motors. Any motor which responded only to the current utterly failed to register returned energy; but, on the other hand, it registered energy which had been sent out, and again on its return by self-inductive loads, thus making a double charge for what the customer had not received at all. It might also be added that the drop in the series coil of the motor meter in question was believed to be very small, and that further improvement in this respect was scarcely necessary. When it was remembered that meters were manufactured which responded to as many as four hundred or six hundred lamps, and were yet sensitive to a single lamp without a high percentage of error, it would be seen that the instrument had reached a fairly advanced stage of development. Cut-off magnets had also been made for opening the circuit of the fine wire or shunt circuit passing through the armature of the meter; the turning off of the last lamp breaking the fine wire circuit, and the turning on of a single lamp or more remaking this circuit. Were it not desirable to keep down the cost of production of the meter, it would be possible to make the instrument of greater refinement. This was not, however, needed in actual commercial practice. The meter had also been made from the first to act as a coulomb-meter, by the use of electro-magnets instead of permanent magnets to affect the damping disk; and in this respect was like the Hummel meter alluded to by the Author. It might be added that the Thomson motor meter had been so modified as to be applicable to the case of arc-lamps in series, and to respond to variations in the voltage. In this case, the armature part of the meter received a constant current in shunt to a small resistance in the main line, while the field-coils of the meter surrounding this armature were of fine wire in shunt to loops of eight or ten arc lamps, and the registration obtained was in proportion to the difference of potential between the ends of the series of lamps.

Mr. G. P. Roux observed, with reference to the first point to which the Author had directed attention, that a meter that would not register accurately all intermediate loads was not worthy of the name of meter. That was, however, the chief defect of many of them. Nevertheless, in practice, a certain error had to be allowed, but should not exceed 2·5 per cent., which was the allowance made in the case of gas meters. The second point bore upon the ordinary inertia of meters which did not start with weak currents. Numerous experiments, made by himself, had convinced him that the majority barely started with one-tenth of the total load, and then with an error of at least 10 per cent. In other words, a 10-ampere meter started with 1 ampere, but only registered 0·9 ampere, beyond which the starting was not always certain. One meter alone, to his knowledge, was without that defect. The Brillié meter, with which many experiments had been made, and which he had himself tried for nearly a year, started with certainty at one-thousandth of the total load. The trials that he had made were with a continuous current meter with 10 amperes at 100 volts. It was guaranteed by the inventor to start with 0·1 ampere, and actually started with 0·01 ampere. Although necessarily inaccurate at that point, there was no real drawback, for one never had to measure such weak currents. At and above 0·1 ampere, it was absolutely accurate up to 12·5 amperes, which was 25 per cent. above its range, and it started at 38 volts. Variations of potential and current of one-tenth per cent. were recorded with a high degree of sensibility. A meter of this type, designed for 2,000 amperes, started with 2 amperes as certainly as with 100. The meter belonged to the class of motor meters, its essential part comprising a movement, the speed of which was proportional to the strength of the current to be measured. Unlike all other motors of this class, the rotation was effected by a motor, whilst the measuring apparatus consisted of an electro-dynamometer that regulated the speed of this motor. The movable coil of the electro-dynamometer carried suspended a disk of red copper, which was enclosed by two sets of permanent magnets, whose opposing poles on the two faces of the disk caused a magnetic field to cut it. This arrangement of magnets turned under the action of a small electric motor. When the current passed, the electro-dynamometer left its equilibrium position and turned the disk through a small angle; the magnet arrangement, on the other hand, began to rotate, and exerted a force tending to restore the disk to the position it had left. The force thus exerted was proportional to the speed of the magnets. This speed was regulated by means of resistances in the circuit of the little motor, introduced and withdrawn by the electro-dynamometer. If the speed was too low, the electro-dynamometer was not brought up to the zero; if, on the other hand, the speed was too high, it passed the zero and exercised a retarding influence. A condition of equilibrium was set up when the attraction of the magnets equalled that exercised by the electro-dynamometer. In actual operation, this condition obtained at each instant, and the speed was continually proportional to the quantity E × C which it was required to measure. Errors due to temperature were absent, owing to the copper disk being of the same metal and conductivity as the coils of the electro-dynamometer; consequently the variations of temperature were the same in both. An experiment had been made in order to ascertain whether variations of temperature could distress the meter. To this end, one had been subjected to a constant temperature of 60° Centigrade for a period of three days, and afterwards re-verified, its indications proving undisturbed. With regard to the consumption of energy by the meter for its own work, that was, in Mr. Roux's opinion, a most important matter, and one which should be taken into consideration in purchasing these instruments. He thought that the consumption of the Brillié meter was exceedingly slight, by reason of the high resistance (10,000 ohms) of the electro dynamometer coil, which was always in circuit. Indeed, for a station working at 100 volts, there would be a continual expenditure of only 1 watt. The consumption of the motor was proportional to the load, and about 3 watts for the full load—a quantity quite negligible in view of the existence of meters which consumed at the rate of 10 watts. Referring to the speed of meters, it was certain that low speeds were to be preferred, and that 480 revolutions per minute at full load were quite allowable.

One important defect, which the Author had omitted to notice, was the internal friction of these instruments. In motor meters, the work of the dynamo, or of the integrating apparatus, did not represent only the work absorbed by the brake, but further, the friction of the instrument. And, although one was struck by the very ingenious devices used to render this friction as slight as possible, it could not be supposed that this friction remained constant. The chief advantage of Mr. Brillié's meter was that the measuring apparatus was quite free from the effects of friction, being entirely independent of the motor. It was, in short, only a relay, which could just as well command a motor of 100 HP. By this arrangement, the speed measured was not a function of the friction ; more or less energy was spent in the motor according to it, but it was always ensured that equilibrium obtained between the force developed by the electro-dynamometer and that exercised upon the disk. If the friction increased, the speed of the motor tended to diminish the currents developed in the copper disk, and its active effort diminished ; consequently the action of the coil of the electro-dynamometer would preponderate ; it would turn to the right, and thus increase the power of the current passing through the motor, which power would increase until equilibrium was restored. The measurement was very accurate, and might be well compared to the action of a good steam-engine governor, which preserved a constant speed in that motor, whatever might be the variations of pressure, friction, or load.

METERS

FOR RECORDING THE

Consumption of Electrical Energy.

METERS FOR RECORDING THE CONSUMPTION OF ELECTRICAL ENERGY.[1]

THE rapid advance that electric lighting from central stations has made during the last few years has brought the question of the construction of instruments for recording the energy used by individual consumers into great prominence. The subject had engaged the attention of inventors for many years previously; but the need was not so pressing, and, numerous as had been the attempts, but few instruments had passed the experimental stage. Hence, the early supply companies were forced to charge their consumers a fixed price per annum based on an average number of hours of burning, such average being of necessity arrived at by guess-work in the absence of any experience. It was found

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[1] This communication was read and discussed at a meeting of the Students on the 11th of December, 1891,

that this system was unsatisfactory to the company and its clients, for in the case of clubs, restaurants and many shops, three hours — the average time assumed—was found to be absurdly small; and, on the other hand, it was too large for many private houses. Endless disputes resulted, and consumers became dissatisfied and ceased to use the light. A large amount of loss was occasioned by persons leaving lamps burning needlessly, because they had not to pay for them; and it is a significant fact that in the case of a large central station in London, the current during the day was sensibly diminished when a large number of consumers were supplied by meter instead of by contract.

The urgency of the demand for meters has brought forth a supply, and there are now in the market several types that are reliable and accurate, and the Author purposes confining his remarks chiefly to these, merely glancing briefly at a few of the best of the early and less successful types.

There are two fundamentally different systems of supply, *i.e.* (i) by continuous, and (ii) by alternating currents; and to each of these belong certain classes of meter that will only work with a particular kind of current, while some are common to both systems; these last are usually dependent for their action on the square of the current.

In all cases it is desired to measure the total amount of energy that has been converted into light and heat in the consumers' lamps and wires, and a meter is an instrument that continuously records the power delivered, and integrates it with respect to time.

In the case of continuous currents, if E be the potential difference, or pressure in volts, between the mains at any instant, and C the current in amperes at that instant through the lamps, then $E \times C$ is the power, or rate at which energy is being supplied in watts; and if t is the time in hours during which the rate is kept up, then ECt is the total quantity of energy in watt-hours used by the consumer in the time *t*. This number divided by one thousand gives the number of commercial or Board of Trade units (B.T.U.) consumed. What the meter has to do, then, is to sum up the successive values of this product.

With alternating currents the measurement of the power is not so simple, for in this case if the mean pressure and the mean current be multiplied together, the product is not necessarily the power absorbed. If the current lags behind the pressure, as it will if the circuit possesses self-induction (and it always does so in practice, though in the case of a bank of incandescent lamps the lag is negligible), the current maximum does not occur at the same instant as the pressure maximum, and the real power is less than that obtained by multiplying together the mean pressure and the mean current. Taking the same units as before, if E be the maximum pressure, C the maximum current, and φ the angle of lag of the current behind the pressure,

$$\text{then the true power} = \frac{EC}{2} \cos \varphi.$$

Since all distribution is effected at constant pressure, it is sufficient to integrate the current only, and to multiply the result by the pressure in the case of continuous currents, and of alternating currents also, if incandescent lamps only are in circuit ; provided in all cases that the standard pressure is closely maintained. This course is adopted in a large number of meters, and is quite satisfactory in practice. If, however, greater accuracy be desired, the principle of the watt-meter must be employed. Here the stress between two coils, one of which carries the main current and the other a shunt current proportional to the pressure, is made use of. The force in the case of continuous currents is proportional to the product of the pressure and current ; but in the case of alternating currents this is only the case if the shunt coil has no self-induction, a condition manifestly impossible to obtain ; it can, however, be sufficiently reduced to render the error very small.

It would be entirely out of place in a Paper of this kind, which aims at a description of actual instruments in commercial use, to enter into a mathematical discussion of the measurement of alternating currents, the matter being fully treated in textbooks in language far more able than the Author's, and to which he could add nothing.

Meters fall broadly into four classes :—

1. Those in which the current to be measured, besides controlling the registering gear, supplies the motive power for it.

2. Those in which the current to be measured controls the registering mechanism, while a separate current supplies the motive power.

3. Those in which the current merely controls mechanism which is driven by some force altogether external to the current, such as a spring or weight.

4. Those in which no gearing is driven,

but chemical action goes on, involving an alteration in mass of a plate of metal.

CLASS 1.

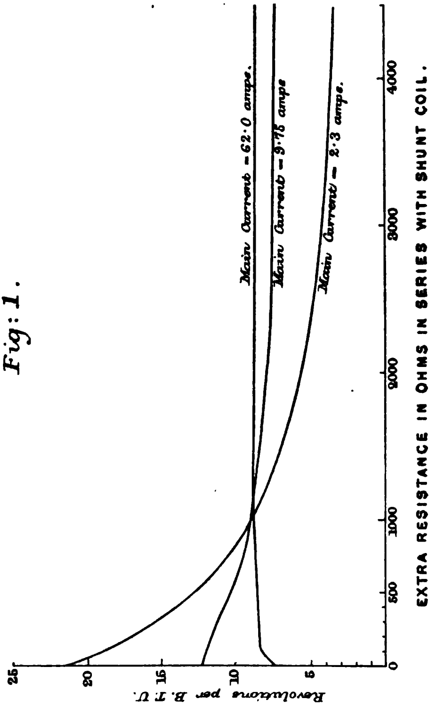
Numerous forms of motor meter have been designed, and some of the most successful instruments in use at the present time are included in this class. The majority are current, and not power-integrators, the pressure being assumed constant as already explained.

Ferranti Meter.—This depends for its action on the fact that when a mass of mercury is cut normally by lines of magnetic induction, and an electric current flows radially through it, the mercury tends to rotate. If the same current that flows through the mercury excites the field, the speed of rotation will be proportional to the square of the current; but mercury being a fluid, its motion is opposed by friction against the sides of the containing vessel with a force that varies as the square of the speed, hence the speed of rotation is proportional to the current.

This principle is equally adapted to the measurement of continuous and of alternating currents, and it has received very great development at the hands of the inventor. It is the meter that is chiefly used by the London Electric Supply Corporation for installations exceeding 40 amperes, and as the Author has had a large experience of it, a detailed description may not be out of place.

When the principle is applied to making a practical instrument, an aluminium fan, mounted on a spindle, is immersed in the mercury, and is carried round by it ; the spindle carries a pinion gearing into a train of counting wheels. This counting mechanism introduces friction that is practically independent of the speed of rotation, and is greater when the meter is at rest than when it begins to move. The whole friction is thus made up of two parts, one varying as the square of the speed, the other independent of the speed ; obviously the relative importance of the latter diminishes as the current, and therefore the speed, increases. In order to compensate for the error that would thus be introduced, a "shunt coil" is provided, *i.e.*, a fine wire winding on the field magnet placed as a shunt across the lamp leads, thus establishing a certain magnetising force independent of the number of lamps alight. The relative importance of this magnetising force manifestly decreases as the main current increases, and this effect is enhanced by a transformer action being set up, whereby the main current generates in the shunt coil an electromotive force oppositely directed to that acting on it, thus further cutting down its magnetising effect. By suitably varying an extra resistance in series with the winding, the compensation can be made practically perfect. In Fig. 1 are plotted three curves that very clearly show the part played by the shunt coil. A constant current was maintained through the main coil, and the current in the shunt coil was varied by altering the extra resistance in series with it, the speed of rotation for successive

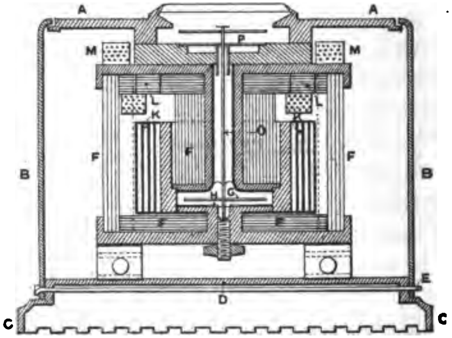
Fig: 1.


Main Current = 62·0 amps.
Main Current = 9·75 amps
Main Current = 2·3 amps.
25
20
15
10
5
Revolutions per B.T.U.
0
500
1000
2000
3000
4000
EXTRA RESISTANCE IN OHMS IN SERIES WITH SHUNT COIL.

values of the latter being noted. Another value was then given to the current in the main coil and the same operation repeated. The results are plotted for three main currents, revolutions per unit as ordinates, and extra resistance as abscissae. It will be seen that, except for very large shunt magnetising forces, the effect of the shunt coil at high currents in the main winding is small. The point in which the three curves cut gives the extra resistance required by the particular meter.

One of the latest forms of this meter is shown in Fig. 2. It is intended for a maximum current of 100 amperes, and with this load on for twenty-four hours does not rise to an excessive temperature. This, it may be noted in passing, is a point that should always be tried for each meter containing iron if intended for alternating currents, for it is found that out of a batch of similar meters several will heat excessively. The cause is somewhat obscure, but is probably due to the laminations of the iron becoming short-circuited. The meter is contained in a well-ventilated brass case, A B C, no wood being used in its construction. The brass cylinder B is slipped on after the leads are fixed, and is secured by a wrought-iron pin, D, passing through it and under the base; a small hole, E, is drilled through the end of this pin, and tape is passed through this and sealed. It is thus impossible for the meter to be tampered with, and the whole arrangement is very compact and convenient. The magnetic circuit F F is closed, except

Fig: 2.



for the gap G, which contains the mercury. The current enters by the central portion H, the rest of the top and bottom of the cavity being covered with vulcanized fibre. The circumference of the bath is uninsulated and by it the current leaves, flowing thence through the main coil K, one end of which is attached to the iron of the magnet, and so out of the meter. The shunt coil is shown at L and the extra resistance at M; the fan is wholly immersed in the mercury and carried by the spindle O which drives the train P.

The following is a test made of a meter of this type :—

TEST OF 100-AMPERE ALTERNATE-CURRENT FERRANTI METER.

Meter started with 0·92 *ampere.*

Current in Amperes.	Revolutions per Board of Trade Unit.	Current in Amperes.	Revolutions per Board of Trade Unit.
1·5	10·4	40·0	16·9
3·0	15·4	50·0	17·0
4·0	17·5	60·0	17·3
5·0	17·3	70·0	17·3
7·5	17·5	80·0	17·3
10·0	17·0	90·0	17·3
20·0	17·0	100·0	17·3
30·0	17·2		

It will be noticed that the uniformity of the constant is most marked, and it has been found, after repeated experiments, that if the meter is adjusted so as to have the same constant at 10 amperes and 100 amperes, the value will be practically the same at all intermediate points.

In the continuous current form, solid cast-iron or steel is substituted for laminated wrought-iron, and the residual magnetism takes the place of the shunt coil.

The following are tests of two of these meters :—

TEST OF 100-AMPERE CONTINUOUS-CURRENT FERRANTI METER. UNSHUNTED.

Meter started with 0·25 *ampere.*

Current in Amperes.	Revolutions per Board of Trade Unit.	Current in Amperes.	Revolutions per Board of Trade Unit.
1·0	16·6	50·0	16·6
10·0	16·4	100·0	16·5

TEST OF 10-AMPERE CONTINUOUS-CURRENT FERRANTI METER. UNSHUNTED.

Metev started with 0·15 *ampere.*

Current in Amperes.	Revolutions per Board of Trade Unit.
1·0	110
5·0	112
10·0	110

An important point in connection with the permanent magnetism of these meters, which renders its use unobjectionable, is that the steel giving the initial field is magnetised to saturation by the largest current the meter is intended to carry, so that every time the full load is on the meter the steel is re-magnetised, and any danger of falling off in strength of field is avoided.

In the latest form, meters of the same capacity are made to have the same constant by adjusting the width of a gap in the magnetic circuit; and by the introduction of suitable gearing the constant is dispensed with and the meter is rendered direct-reading. These meters are "double-sealing," *i. e.* the working parts can be sealed by the local authority against any possible tampering by the supply company, while the latter can independently seal the terminals in order to protect itself from fraud on the consumer's part.

Some of these mercury meters have been at work for two or three years without any attention, though it is desirable to clean the trains and mercury once a year. The following case will give some idea of the constancy that may be attained by this kind of meter. The meter, an alternate-current one, was installed on the 3rd of December, 1887, and removed on the 25th of February, 1890, during the whole of which time it received absolutely no attention. It was, however, read weekly, so that its performance could be noted, and was constantly at work, except for one week, when it was removed from one consumer's installation—the consumer having ceased to take light from the company—and placed in another's. During the period named the fan made rather more than 9,500,000 revolutions. The tests of the meter before it was put on the circuit and after it was removed are as follows :—

TEST MADE BEFORE METER WAS INSTALLED.

Meter started with 0·8 *ampere.*

Current in Amperes.	Revolutions per Board of Trade Unit.	Current in Amperes.	Revolutions per Board of Trade Unit.
1·9	17·77	28·75	17·70
4·6	17·77	57·0	17·77
6·4	17 73	95·0	17·73

TEST MADE AFTER OVER TWO YEARS' USE.

Meter just failed to rotate with 2·17 *amperes.*

Current in Amperes.	Revolutions per Board of Trade Unit.	Current in Amperes.	Revolutions per Board of Trade Unit.
10·2	14·58	70·0	17·83
20·2	16·63	89·6	17·81
50·2	17·93		

The increased current required to start the meter, and the diminished constant at low currents, are obviously due to the train requiring cleaning. The constancy at the high currents is most satisfactory.

Forbes Meter.—Another meter adapted equally to alternating and to continuous currents is that invented by Professor G. Forbes. It is based on the heating property of the current, and consists of a horizontal spiral of iron wire, over which is mounted, on a delicate pivoted suspension, a system of mica vanes. Convection currents are set up in the air by the hot wire, and these, rising against the vanes, urge forward the ring on which they are mounted, its motion being registered by a train of counting wheels.

The standard form at present made has a maximum capacity of 30 amperes, and the heated conductor consists of two concentric wires connected together by a number of fine wires. The current enters at a point in the circumference of one circle, and dividing between its two halves, flows by the fine wires into the other, and leaves by a point in its circumference.

In order to increase the starting power of the meter, a small weight is attached to a cord passing over a pulley and round a drum on the last wheel of the train ; this tends to drive the train, and so gives the vanes less work to do.

This meter gave great promise when it first appeared, but it does not seem to have met with much favor, probably because, resembling, as it does, a laboratory instrument in delicacy, it is found unsuitable for practical work. It is liable also to be affected by external changes of temperature and by the temperature of its case not being uniform.

Hookham Meter.—This consists of a motor driven by the current to be measured, the motor being retarded by eddy currents set up in a copper disk. A tungsten-steel permanent magnet with cast-iron pole pieces provides a constant field, and in this is placed the armature, which consists of flat coils laid on a copper disk, the latter serving the double purpose of a support for these coils and of a brake, the latter effect being produced by the eddy currents set up in it. The armature spindle rests on friction-wheels, so that a small force will cause it to move, and with a view to still further diminish friction, mercury contacts are provided, instead of brushes, for the commmutator.

The theory of the instrument will be plain from the following considerations. The work done in a given time is proportional to the attraction between the disk and the field, and to the speed. Now in a constant field the electromotive force generated in the disk varies as the speed, and since this acts through a constant resistance, the eddy currents also vary as the speed; hence the work done is proportional to the square of the speed. The work supplied by the armature is proportional to the driving force and to the speed, but the driving force varies as the current; hence the work supplied in a given time varies as the current and the speed; but it has been shown that the work done is proportional to the square of the speed ; hence it follows that the speed is proportional to the current.

The principle can be adapted to either alternating or continuous currents, but so far instruments for the latter class of current only have been constructed.

The meter is adjusted so that the dials show Board of Trade units, and it thus possesses the important advantage that its indications have not to be divided by a constant. This is brought about by varying the strength of the field in which the armature revolves, by short-circuiting more or less than the magnetic circuit.

Some difficulty was experienced in passing the whole current through the mercury contacts, so that in the latter form all the motors are made to carry 5 amperes, and are shunted with a German silver resistance that allows the requisite proportion of current to pass. This is open to two serious objections, viz.: (i.) any error in the meter is magnified, since a portion only of the current drives the motor ; (ii.) if the resistance of contact of the mercury varies (as it is almost certain to do), the motor does not get its right proportion of current, and its indications are therefore fallacious. The mercury being exposed to the air and being subject to sparking, is rapidly oxidised, and in practice much trouble is experienced on this account, the meter requiring, after a time, a considerable current to start it. The permanent magnet is also an objectionable feature, though it is said that little change is found to occur in the field on account of the care taken in the preparation of the magnets, and because the gap in the magnetic circuit is small.

The author has not not had the opportunity of testing any of these meters, but it is stated that a 20-ampere meter starts with 0·4 ampere ; and that with 0·6 ampere the error is 25 per cent.; with 1·2 ampere it ts 10 per cent.; while after 2·5 amperes the error is negligible.[1]

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[1] Since this Paper was read, Mr. J. H. Tonge, Stud. Inst. C. E., has favored the Author with the following test of a 100-ampere Hookham Meter for continuous currents. With

Elihu Thomson Meter.—Another meter closely resembling this in principle has been lately developed by Professor Elihu Thomson, and appears to be free from some of its defects. A motor is provided, having its armature wound with fine wire and excited with a shunt current, and its fields, without iron, excited by the main current. Since the field is proportional to the current, and the armature current to the pressure, the driving force is proportional to the watts, and hence the instrument is a watt-hour meter. The opposing force, as in the Hookham meter, is due to eddy currents, generated in a copper disk, which is rotated by the armature in a constant field set up by permanent magnets. It is thus

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pure mercury in the contact cups, the meter started with 1 ampere, and with 100 amperes it read 1 per cent. low; with 50 amperes, 4 per cent. low; with 20 amperes, 9 per cent. low; and with 3 amperes 17 per cent. low. When, however, ordinary commercial mercury which had been in use for a short time was substituted for pure, 3·5 amperes were required to start the meter, and with 100 amperes it read 8 per cent. low. This conclusively proves the statement made as to the error introduced by the variable resistance of the mercury contacts.

open to one of the objections to that meter, but is free from the mercury contacts and variable shunt resistance.

Falling off in strength of the permanent magnets is much to be apprehended, since they are under peculiarly trying conditions: the eddy currents, as in the Hookham meter, tend to demagnetise the magnets; and in the alternating form they are subject to the mechanical vibration which always accompanies this class of current. Another source of error is the friction of the motor brushes, which is likely to alter with wear and dirt.

Time alone can show the importance of these objections; there can be no doubt that when new the meter is capable of giving indications of great accuracy, as the following test proves :—

TEST OF 25-AMPERE ELIHU THOMSON METER.

Meter started with 0·4 *ampere.*

Current in Amperes.	Pressure in Volts.	Power in Watts.	Revolutions per Board of Trade Unit.
24·9	100	2,490	10·14
23·9	100	2,390	10·02
22·9	100	2,290	10·02
21·9	100	2,190	10·08
20·9	100	2,090	10·02
19·8	100	1,980	10·02
18·8	100	1,880	9·96
17·9	100	1.790	10·20
17·0	100	1,700	10·20
15·9	100	1,590	10·02
14·9	100	1,490	9.96
13·9	100	1,390	9.96
12·9	100	1,290	9.90
11·9	100	1,190	9.90
10·9	100	1,090	9·78
9·7	100	970	9·78
8·6	100	860	9·84
7·8	100	780	9·84
6·8	100	680	9·72
6·0	100	600	9·72
4·8	100	480	9·72
4·0	100	400	9·60
3·0	100	300	9·42
2·0	100	200	8·70
0·99	100	99	7·44
0.78	100	78	6·66
0.58	100	58	4·98

In order to try the effect of varying the pressure as well as the current, the following tests were made of the same meter :—

Current in Amperes.	Pressure in Volts.	Power in Watts,	Revolutions per Board of Trade Unit.
24·8	108	2,678	9·96
20·1	108	2,171	9·96
15·2	108	1,642	9·72
10·0	108	1,080	9·66
24·9	90	2,241	10·14
20.1	90	1,809	10·02
14.9	90	1,341	9·66

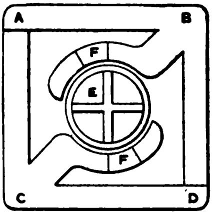
The extremely low speed of the armature, and its property of stopping almost dead immediately the current is switched off, are noticeable points, and the former is an important advantage, as tending to lengthen the life of the meter by diminishing the wear.

In measuring currents supplied on the three-wire system, the neutral wire does not enter the meter, but the others pass each through one of the two field-coils. The armature circuit is connected across the outer conductors, being thus excited with 200 volts.

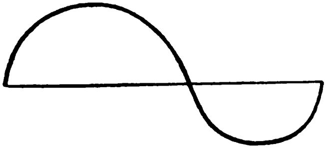
When it is desired to measure the current conveyed by the high-tension mains from an alternating central station, the high-tension lead is taken through the field-coils, while the armature circuit is excited by the secondary of a special converter, having its primary connected across the high-tension mains.

Ferranti-Wright Meter.—This is, in effect, an alternate-current motor, and depends for its action on one of those peculiar phenomena which take place when a conducting circuit is cut by lines of magnetic induction which are varying rapidly in direction and intensity. The meter is shown in plan diagrammatically in Fig. 3. The four limbs A B, B D, D C, C A, consisting of laminated wrought-iron, are wound so that B and C are opposite poles; each of these is fitted with a pole-piece consisting of an elongated horn, forming part of a circle within which is placed a conducting disk E, usually, but not necessarily, of iron. Each horn is surrounded by a closed conducting circuit of low resistance, consisting of one or more copper bands slipped over them, shown at F F. It is impossible to give a full explanation of this remarkable meter in a few words, but perhaps the following will make its

Fig: 3.



principle fairly clear. Suppose a current to rise in the magnetizing coils from zero to a maximum, then it tends to magnetize the iron, and the induction in the iron follows the successive values of the current in the part enclosed by the coils nearly instantaneously, but in the horns it lags behind the current, partly on account of hysteresis, but chiefly because its change generates in the circuit F F currents that tend to magnetize the iron in the opposite direction. The action of the closed copper circuit is to hinder the rise of magnetism in the iron, giving it a kind of magnetic self-induction, in just the same way as iron gives to an electric circuit ordinary self-induction. Now suppose, for a single rising current, there be substituted a rapidly alternating one, then any point in the horn will experience a series of waves of magnetism following one another, and successive points along the horns will be subject to waves of diminishing amplitude (for the maximum induction falls off towards the tips), differing in phase from one another on account of the lag above mentioned. The state of the induction in either horn at any instant may be represented by a curve such as is shown in the diagram, the lag being sufficiently great in some cases to cause the induction to be of



TEST OF 20-AMPERE FERRANTI-WRIGHT METER.

Meter started with 0·65 *ampere.*

Current in Amperes.	Revolutions per Board of Trade Unit.	Current in Amperes.	Revolutions per Board of Trade Unit.
2·5	117·3	12·5	115·2
5·0	116·1	15·0	116·2
7·5	114·3	17·5	114·5
10·0	114·9	20·0	116·4

The beautiful simplicity of these meters, which have practically nothing to get out of order, has made them a most valuable acquisition, and they are almost exclusively used by the London Electric Supply Corporation for installations up to 40 amperes. They have proved to be reliable, and give practically no trouble as regards repairs; they are moreover light, compact and easy to instal.

In the latest form of these meters it has been found possible, by great care in manufacture, to so diminish the friction as to render the shunt winding unnecessary. The field-magnets consist of two vertical limbs with horizontal curved horns embracing the armature ; the horns are made movable, so that their distance from the armature can be varied, and the instruments adjusted to have the same constant. They are then rendered direct-reading by proportioning the gearing. The meters are "double-sealing," and the plate protecting the terminals covers also a small screw that admits of the armature and spindle being raised from the jewel during transit, without interfering with the Local Authority's seal. A minor point of difference from the older type is the substitution of aluminium for mica fans.

The following is a test :—

TEST OF 10-AMPERE FERRANTI-WRIGHT METER.
UNSHUNTED.

Meter started with 0·4 *ampere.*

Current in Amperes.	Revolutions per Board of Trade Unit.	Current in Amperes.	Revolutions per Board of Trade Unit.
10·0	240	3·0	240
9·0	238	2·0	238
8·0	242	1·0	224
7·0	247	0·8	209
6·0	240	0·6	193
5·0	238	0·4	198
4·0	243		

The unshunted form of this meter is very suitable for recording the quantity sent out through the high-tension mains of a central station, and it has been applied to this purpose.

Shallenberger Meter.—Like the last, this is an alternate current motor. It consists of two coils with their axes set at an angle of 45° to one another, both surrounding a horizontal iron disk, free to revolve on a vertical axis ; the plane of the disk is at right angles to the planes of the coils. One of these coils carries the current to be measured, the other is simply closed on itself. The current in the former induces in the latter a current which is a quarter of a period behind itself, and the effect of this is that the induced current, reversing as it does with the inducing current, attracts the poles successively set up by the latter, so producing continuous rotation. The motion is retarded by aluminium fans. The following is a test of a 100-ampere meter :—

TEST OF 100-AMPERE SHALLENBERGER METER.

Meter started with 3·5 *amperes.*

Current in Amperes.	Revolutions per Board of Trade Unit.	Current in Amperes.	Revolutions per Board of Trade Unit.
5	13·0	50	13·3
10	12·8	55	13·1
15	13·1	60	13·4
20	13·3	65	13·3
25	13·3	70	13·3
30	13·0	75	13·3
35	13·3	80	13·1
40	13·3	85	13·1
45	13·3	90	12·5

It will be observed that the constant is remarkably good, but the starting power is distinctly poor.

A test of a smaller size is appended :—

TEST OF 10-AMPERE SHALLENBERGER METER.

Meter started with 0·4 *ampere.*

Current in Amperes.	Revolutions per Board of Trade Unit.	Current in Amperes.	Revolutions per Board of Trade Unit.
0·6	17·9	5·8	18·1
1·0	17·7	7·0	18·6
1·9	18·5	8·2	17·9
2·9	18·0	9·0	17·5
3·9	18·0	10·0	17·6
4.9	17·9		

Although the above results are given in the form of a constant, the meters are direct reading, the adjustment to identical constants being effected by altering the angle between the planes of the closed and inducing coils. The latest form is arranged to be "double-sealing."

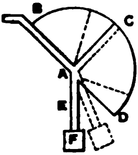
This meter is very largely used in America by the Westinghouse Company, and in London by the Metropolitan Electric Supply Company. The London Electric Supply Corporation has also a few in use, with satisfactory results.

Slattery Meter.—This depends on the same principle as the Shallenberger, but differs from it in having a light copper cylinder in place of the iron disk, and in the way in which the motion of the revolving cylinder is retarded. Each vane consists of two quadrants of a circle A B C, A D C (see Fig. 5), the lower being pivoted about the centre A; it has attached to it an arm E weighted at F. When the speed increases, the weight flies out and raises the quadrant A C D, which slides behind A B C, thus reducing the surface exposed to the air-resistance. This is a different way of accomplishing the result obtained in the Ferranti-Wright meter by slitting the fans.

Class 2.

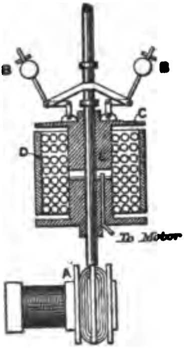
Hopkinson Meter.—One of the earliest practical forms in this class is that invented by Dr. J. Hopkinson, M. Inst. C.E., and, probably, if the present demand had existed at the time at which it was brought out, it would have received considerable development. This meter is shown diagrammatically in Fig 6. A high-resistance motor A is placed as a shunt across the lamp leads, and is so arranged that when

Fig: 5.



excited it causes a pair of governor balls B B to rotate; the centrifugal force of these tends to raise an iron core C, which is attracted downwards by the main current passing through the solenoid D. The core carries a contact E, which makes and

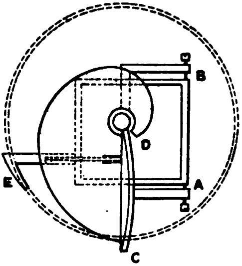
Fig: 6.



breaks the motor circuit, and is so adjusted that when no current flows through the solenoid the circuit is broken. Directly a lamp is turned on, the core is attracted downwards and the motor revolves, increasing its speed until the governor balls cause its circuit to be broken. Now the centrifugal force is proportional to the square of the speed, and the attraction of the solenoid for the core is, within certain limits, proportional to the square of the current, hence these two forces will exactly balance, and the motor will revolve with a speed proportional to the current, for, if it rises above the proper speed, its circuit is broken and the speed falls ; and if it falls below its right value, its circuit is made and its speed increases. The number of revolutions are recorded by a train of counting wheels driven by a worm from the motor spindle.

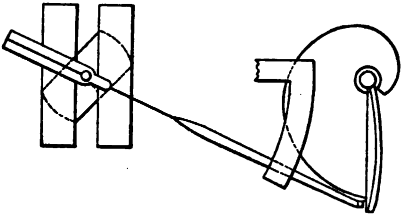
Frager Meter.—This is, perhaps, the most successful of this class of meter. It is an improvement on an earlier form known as the Cauderay, and consists essentially of the combination of an ammeter or wattmeter, a clock and an integrating device connected to a system of counting wheels. The meter is adapted to either alternating or continuous currents—the wattmeter being always used in the former case. Its latest form may be thus described. The movable coil of the wattmeter is of German silver wire wound on a wooden bobbin, a noticeable point being that, contrary to the practice of most makers, the whole of the shunt circuit is wound inductively and is movable, instead of only a comparatively small portion being so wound and the rest of the circuit formed of a non-inductive extra resistance. The coil is suspended by a wire of phosphor bronze, and carries a long lever, formed of aluminium in the larger sizes and of brass in the smaller, balanced with a brass counterpoise so as to hang horizontally. The end of this lever is furnished on its under side with a wedge-shaped piece of steel, and hangs over a horizontal cam or snail, shown in Fig. 7, which is kept in slow rotation by means of a ratchet-wheel worked by a pawl from a balance wheel, maintained in oscillation by a shunt current. The snail is carried by a cradle, hinged at A B (Fig, 7), and pressed upwards by a spring. Rigidly attached to the spindle carrying the snail-cradle, and running along the straight edge of the snail and projecting beyond it, is a piece of steel C D, beveled on its edge, which is circular, having the suspension wire for centre. As the spindle rotates, this beveled edge comes in contact with the steel wedge on the lever, and causes the latter to rise and to jam against a brass sector placed over it. If no current passes through the main coil of the wattmeter, the lever stands at zero, and, as rotation proceeds, it simply drops off the

Fig: 7.



piece C D. If, however, the lever is deflected when the engagement takes place, the lever drops on to the snail, depresses it, and causes a pawl E which it carries to engage with a ratchet-wheel, which ratchet-wheel drives a counting-train. Rotation goes on, and, as long as the lever remains on the snail, it is locked, and the counting-wheels continue to register. As soon as the lever reaches the round edge of the snail it drops off, the snail rises, and the pawl ceases to drive the counting-train. Now an inspection of the snail will show that its shape is such that the greater the deflection of the lever at the instant of its engagement, the longer it remains on the

Fig: 8.

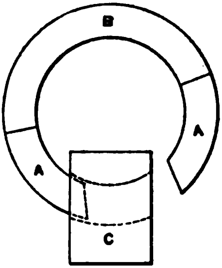


snail, and that it must drop off once every revolution. The action of the instrument is, therefore, this: at equal intervals of time, this interval being the time taken by one complete revolution of the snail (two hundred, three hundred or four hundred seconds, according to the size of the meter) the lever is locked in the position which it happens to occupy at the instant, remains on the snail for a time proportional to its deflection, and then quits it, having caused a certain amount to be registered on the dials. Now this amount is that which would have been used in the time occupied by one revolution of the snail, if the current had retained the value it had when the lever engaged. If the current changes, no account is taken of the alteration until the next time the lever engages, when the current is again assumed to remain constant during one revolution. What the instrument does, then, is to take a reading of the wattmeter so many times an hour, to multiply each reading by the time of one revolution, and to add all these successive products together on the dials.

The following are details of the several parts :—

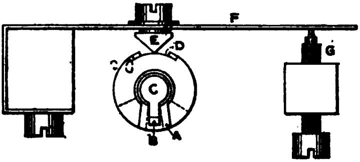
The balance wheel is furnished with a flat chronometer spring, and consists of a nearly complete circle, formed of two pieces of soft iron A A, Fig. 9, united by a brass piece, B. A short solenoid C excited by a shunt current, is so placed that when the wheel is at rest the soft iron cores are unsymmetrically placed. At the top of the spindle carrying this wheel is the

Fig: 9.



contact-making device shown in Fig. 10. Two little steel plates, one above the other, shaped as shown, are mounted loose on the spindle ; the top one has a V-shaped slot A, in which works a pin B attached to the spindle C, from which it derives an oscilating motion ; the lower plate has a much wider V-shaped groove, shown dotted, and in this works a pin projecting downwards from the upper plate. Each plate has a depression, shows at D, and a knife-edge E fixed to a spring F, one end of which can make contact with a contact-screw G, bears against the plates. When the depressions in the two plates are opposite the knife-edge it drops in, and contact is made at G,

Fig: 10.



Full Size.

completing the circuit through the solenoid. If the amplitude of vibration is small, the depressions in the two plates correspond; but if it becomes large, the lower plate is carried round by the upper one, and left so that it prevents the knife-edge from falling. When the amplitude diminishes, contact is again made and a fresh impulse given.

The counting-gear is connected to the snail-spindle by means of a pair of bevel-wheels, and by adjusting the number of teeth in them the meters are made to indicate Board of Trade units on the dials, however much the constants of the wattmeter may vary.

This meter is certainly ingenious, but evidently highly complicated. When carefully adjusted and protected from vibration, it is capable of giving accurate results with a steady current; but under the conditions of actual practice it labors under disadvantages, among which may be mentioned :—

(i.) The necessity for careful levelling and adjusting *in situ*, thus making it uncertain whether the test made before it is sent out will apply when it is installed in the consumer's house.

(ii.) So many working parts are liable to get out of order.

(iii.) In cases where the amount of light used is constantly varying at short intervals of time, as in a theatre, indications far from the truth may be given. Small variations in current, due to unsteady running, will cause the lever to oscillate, and it may therefore become locked at the wrong point.

Richard Frères Meter.—Like the Frager, this is an intermittent watt-hour meter; but it has this important advantage—its readings are separated by intervals of only fifteen seconds. It comprises a clock, wound electrically four times a minute, a watt-meter, and a train of counting wheels. The following cycle of operations is gone through every fifteen seconds. At a given instant a shunt circuit is made through an electro-magnet, the armature of which is attracted and winds the clock, the circuit being immediately broken again. After ten seconds another shunt circuit is closed, causing a current to flow through the movable fine wire coil of the wattmeter and through an electro-magnet actuating a friction clutch. This clutch, under normal conditions, mechanically connects the movable coil with the counting train, but when pulled back it allows the coil to move without affecting the train. When the contact is made the clutch moves first, its moment of inertia being much less than that of the wattmeter ; the coil then deflects, a dash-pot steadying it quickly ; the current flows for five seconds and then is interrupted, the clutch flies back by means of a spring and the wattmeter returns to zero, carrying with it the first wheel of the train through an angle corresponding to its deflection. The clock-winding contact is again made and the same series of operations gone through as before.

This meter is in use in France, but has only recently been introduced into England ; it is at present only used for continuous currents, but will doubtless soon be applied to alternating currents also. The Author has had no experience of the meter, but the number of contacts and the complication of its parts will probably be found serious drawbacks.[1]

CLASS 3.

The majority of the meters in this class are founded on Professor Ayrton's ergmeter, which consisted of two clocks regulated to keep exactly the same time. One of these had a magnet in place of a bob at the end of the pendulum, and beneath it was placed a coil carrying the current to be measured ; the magnet being attracted by the coil when the current flowed through it, the pendulum was accelerated, and the clock gained. The difference in time of the two clocks was thus a measure of the quantity of electricity that had passed.

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[1] This instrument must not be confounded with the Richard Freres recording ammeter, which is a very satisfactory apparatus for a different purpose, and hardly comes within the scope of this paper.

There have been numerous improvements on the original idea, the chief being embodied in the Aron and Oulton-Edmundson meters.

Aron Meter.—In this the two clocks are enclosed in one case, and their wheel-trains are connected to a differential gear, consisting of two bevel-wheels, one driven by each clock. Between these, and gearing into both, is a bevel wheel free to revolve at one end of a spindle, the other end of which carries a counterpoise ; to the middle point of this spindle, and at right angles to it, is rigidly fixed a second spindle connected to a counting train. If the large bevel wheels both revolve at the same speed, the intermediate wheel simply revolves on its axis ; but if one goes faster than the other, the intermediate wheel, in addition to revolving, rolls on the large wheels by an amount depending on their difference in speed, and in so doing twists the counting spindle.

This meter is made in two forms, viz. (i.) that just described in which the pendulum carries a magnet ; this is adapted to measure continuous currents only, and is a current integrator; (ii.) that in which the magnet is replaced by a fine wire coil oscillating inside a solenoid; this is adapted to either continuous or alternate currents, and is a watt-hour integrator. The former is in very extensive use, and all employing it speak highly of its performance. It is open to the objection already referred to in connection with the Frager meter, that it has to be adjusted *in situ*, for it is a fact well known to clockmakers, that a clock once shifted always requires regulating, no matter how carefully it may have been moved. The permanent magnet is liable to change, and it is found necessary to redetermine the constant of a meter that has been in a house where a short circuit has occurred, the magnet being weakened by the excessive current. The clocks have to be wound up at least once a month, and if one of them by any mishap should stop, the whole record is destroyed. It is the practice in some central stations to synchronise the meters every three months; it is then found that about half are slow and half fast, but the error is not serious. An evidence of accuracy is afforded by a meter at the station agreeing with the sum of the readings of the consumer's meters within, it is stated, a small percentage.[1]

The second form is seldom used except for alternating currents, and with these it is extremely difficult to get an accurate test in the lower part of the scale, on account of the great length of time required in order to get a reading and the necessity for having the pressure and current observed during the whole run, since it cannot be relied on to remain steady as in the case of continuous current where cells can be used. The following is a test of the higher part of the scale of this type :—

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[1] Since this Paper was read, the Author has been favored by Mr. J. H. Tonge, Stud. Inst. C. E., with the following test of a 100-ampere continuous current Aron meter. The instrument read ½ per cent. low with 100 amperes, with 50 amperes, and with 20 amperes, and 10 per cent. low with 1 amperes. In forty-eight hours the difference in time between the two pendulums was one complete period.

TEST OF 200-AMPERE ALTERNATE-CURRENT ARON METER.

Current in Amperes.	Pressure in Volts.	Board of Trade Units per Division.
200·1	100	1·071
190·2	100	1·081
180·0	100	1·075
171·0	100	1·101
159·7	100	1·063
150·0	100	1·068
140·3	100	1·065
130·0	100	1·066
120·0	100	1·070
110·3	100	1·055
100·0	100	1·057
90·3	100	1·056
80·0	100	1·102
70·0	100	1·083
60·0	100	1·068

The meters are now made direct reading, and are provided with an attachment for keeping the clocks in synchronism when no current is on, the difficulty in ensuring this being the chief objection to the meter. It is extremely simple, consisting merely of a light, very slack thread joining the two pendulums and having a small weight hung at its middle point. It effects ing the fine wire coil that it can deflect on either side of its position of rest, thus driving the counting train either way according to the direction of the current. It has also been arranged that if a fixed loss in the battery be assumed, it can be allowed for by inserting a resistance in series with the fine wire coil when charging, thus making the meter register only the percentage of the charging current that will be returned.

Oulton-Edmundson Meter.—In this the ordinary pendulums are replaced by horizontal balances oscillating at about one-quarter the speed, the torsion being supplied by a straight flat spring which also serves as a suspension. The two clocks are driven by one mainspring. The controlled pendulum carries two fine wire coils, one swinging within the main coil, and the other above it. Each of the movable coils consists of two circuits, one placed across the lamp leads in the ordinary way, the other forming a shunt across the main coil; the small current passing through this second circuit is stated to be required in order to raise the constant at the higher readings. This meter in its present form has only recently been introduced.

Kelvin Meter.—One of the latest additions to this class of meter comes from the hands of Lord Kelvin, the inventor who has produced so many electrical measuring instruments of unsurpassed accuracy. As a laboratory instrument, no doubt the meter about to be described is extremely accurate, but it may be doubted whether it is suitable for practical use. In the first place, it is somewhat unreasonable to expect a consumer to descend every day to his coal-cellar, it may be, in order to wind up an instrument of which he is, in all probability, afraid and looks upon as some infernal machine. Next, it has working parts of extreme delicacy and is unsuitable to put into the hands of an ordinary lineman. Lastly, it is preferable to have a continuous rather than an intermittent integrator.

The instrument is a combination of a weight-driven clock which automatically breaks the circuit when it requires winding, an ampere balance and an integrating cam. A fixed coil carries the main current, and in front of it is placed a fine wire coil carried at the end of a vertical aluminium lever free to turn on knife-edges about a horizontal axis. The lower end of this lever has attached to it a train of counting wheels, the first one of which can roll on a cylindrical cam which is kept revolving at a constant speed by means of the clock. When a current passes through the main coil the other is repelled, and the rolling wheel, which originally stood clear of the cam, moves over it, is raised by it, and rolls on its surface, thus actuating the counting wheels. Now the cylindrical surface of the cam is cut away screw fashion, so that, when at one end of it, the wheel only rolls for a small portion of its revolution, and at the other, remains on it for the greater part of a revolution, the time it remains on being proportional to the current corresponding to the position of the lever. A series of grooves are cut on the surface of the cam so that, once engaged, the wheel cannot shift sideways. A scale is provided over which the lever moves, enabling the instrument to be employed as an ampere gauge and its indications to be checked. The constant of the instrument can be altered so as to adapt it to various currents, by altering the weight on a horizontal rod projecting from the movable arm, and by altering the height of a nut on a vertical screw.

CLASS 4.

Edison Meter.—This is a meter adapted to continuous currents only, and depends for its operation on the electrolytic action of the current. A definite portion of the current to be measured is shunted through a bath containing a solution of zinc sulphate, the electrodes being of amalgamated zinc. The meter in its latest form contains three essential parts:—(i.) the electrolytic cell and compensating coil, (ii.)

the shunt resistance, and (iii.) a device for keeping the electrolyte from freezing. The case of the meter is of well-seasoned hard wood, specially prepared to exclude air and to secure good insulation, and its front is closed by a substantial sheet-iron door.

(i.) The cell. This is of bottle form, and is covered to avoid evaporation. It is partially filled with a 10 per cent. zinc sulphate solution in which are suspended zinc plates supported by screws and nuts on ebonite distance pieces, connection being made to them by copper rods held by spring clips. The plates are prepared by being first thoroughly cleaned, then covered on the top and for a short distance up the rod with asphalte varnish, and, lastly, amalgamated and dried. The positive plate is weighed before being immersed. The size of the plates is regulated by the maximum current the meter is intended to carry, the quantity of zinc allowed for being at the rate of 150 milligrams per month for every ampere of nominal capacity. If the meter is likely to run at its full load for a large number of hours during the day, a larger cell is required than the above amount would give. In calculating the quantity that has passed through the meter, one ampere flowing for one hour is taken as depositing 1,224 milligrams of zinc. The counter-electromotive force of the cell decreases as the temperature rises, and its resistance also falls ; in order to compensate for the error thus introduced, a copper coil, the resistance of which of course increases with the temperature, is placed in series with the cell, and is so adjusted that the effective resistance of the combination is identical at 50° Fahrenheit and at 86° Fahrenheit, varying about 1 per cent. between these two points. As regards the change of effective resistance with change of current, it is found that the increase in counter-electromotive force is about compensated for by the fall in resistance of the cell.

(ii.) The shunt resistance is of German silver, and has such a value that $\frac{1}{975}$th part of the whole current flows through the cell. The resistance of this material varies 1 per cent. for every 45° Fahrenheit change in temperature, and the maximum temperature attained by the meter is about 120° Fahrenheit; hence the error from this source does not exceed 2 per cent.

(iii.) The cell is kept from freezing by means of an incandescent lamp placed in the case of the meter and automatically lighted by means of a thermostat when the temperature falls below a certain value. This portion of the apparatus consists of a compound metallic strip which alters its curvature when the temperature falls, completing the circuit through the lamp. The contact point is carried by a screw having a pitch of $\frac{1}{48}$-inch, with a hexagon head, the faces of which are numbered. In this way the temperature of contact can be adjusted to within 2° Fahrenheit.

A curve given by Mr. W. J. Jenks, in a paper on this meter, read before the American Institute of Electrical Engineers, shows that after 3 amperes the rate of deposit is absolutely constant up to 20 amperes; the meter having, therefore, a sevenfold range, and registering with the smallest current, the error is in favor of the consumer.

The chief objections to this meter are:—the remarkably small fraction of the current that is measured—any error, either in deposit or in weighing the plates, being multiplied nearly a thousandfold; the necessity for the consumer relying entirely upon the good faith of the supply company for the accuracy of his account—it being absolutely impossible for him to check his consumption from day to day, or to ascertain for himself the amount registered by his meter; and the constant attention required—the plates having to be removed every month, weighed and replaced.

This meter is in extensive use in America, and was used with satisfactory results at Eastbourne before the system was changed to an alternating current one; it has not, however, met with much favor in this country.

Lowrie-Hall-Kolle Meter.—This meter attempts to apply the electrolytic method to the measurement of alternating currents, and was worked out by the three inventors whose names it bears when they altered the system at Eastbourne from continuous to alternating, the Edison meter having given, as already stated, satisfaction in the former case. In series with the converter is placed a secondary cell, giving a pressure of 2 volts, and an electrolytic bath ; the effect of this is to raise the positive wave bodily by 2 volts, and to diminish the negative wave by the same amount, the effect being the equivalent of two volts always acting in one direction through the circuit, the current flowing being proportional to the number of lamps turned on. The whole current thus passed through the secondary cell, but, so far from it having any ill effect, it seemed to prevent sulphating. It was found that in a suitable electrolytic solution any metal can be by this method deposited by an alternating current, and the quantity so thrown down used as an indication of its amount.

Improvements in other types of meter prevented this being brought to a state of perfection in spite of its being fairly promising. It was, however, open to at least one serious drawback, namely, if the alternating current was switched off, and any lamps left turned on, the cell discharged through them and caused a registration to be effected in the electrolytic bath; moreover, the secondary cell had to be recharged every three months, and there can be little doubt that the inventors would have had trouble with the direct electrolytic action of the alternating current, for it has been shown that without any secondary battery being in circuit, such a current will cause deposition of an uncertain amount, depending on the size of the electrodes.

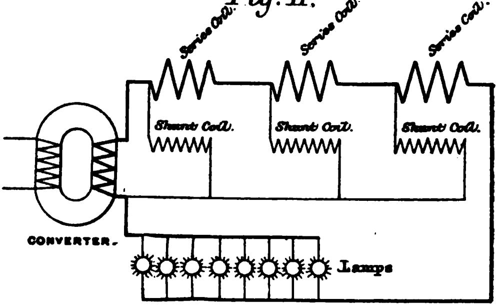
TESTING OF METERS.

In the commercial employment of meters, an important matter is their efficient and rapid testing; and it may be of some interest if the Author describe the arrangements designed and used by him for testing the meters employed by the London Electric Supply Corporation. Their system being an alternating one, only meters adapted to this class of current are provided for. The kinds used are Ferranti mercury, Ferranti-Wright and Frager.

The method adopted in testing the mercury meters is to string a number together with their main coils in series with one another, and with an adjustable non-inductive resistance, the shunt coils being connected in parallel across the converter terminals.

It may be well here to call attention to a source of error that is likely to be overlooked in testing any kind of shunted meter. When in use, the shunt coil has one end attached to the shunt terminal and the other to the converter end of the series coil. If the meters be connected in series, each being allowed to feed its shunt in the ordinary way, two errors will be introduced, as an inspection of Fig. 11 will show—(i.) With large currents in the series coils, the shunt of the meter nearest the converter is the only one receiving its full pressure (100 volts); the second has a pressure that is less than the 100 volts by an amount equal to the drop of pressure in the first; the third is deficient by the drop in two meters, and so on, the last of a long series receiving much less than 100 volts. (ii.) The last meter is the only one that has flowing through its series coil the current that is measured; the last but one receiving in addition to this the shunt current of

Fig: 11.



the last; the third from the end those of the last two; and so on to the one nearest the converter, which receives in addition to the measured current, the sum of all the shunt currents of the other meters. These two errors are easily and completely disposed of by running a separate lead from the converter to excite them, as shown in Fig. 12.

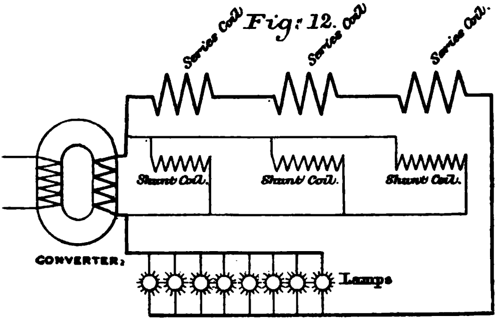


Fig. 12.

To resume, the reading of the dials having been noted, the desired current is thrown on, and kept on for a time sufficient to obtain a reading of such a magnitude that an error of ± 0·1 would not affect the constant more than 1 per cent. It is then thrown off, and the reading is taken when the meters have come to rest. The number of revolutions per hour shown by the dials having been calculated from the difference of the readings, it is divided by the product of the current and the pressure ; this gives the number of revolutions per watt-hour, and, when multiplied by one thousand, the "constant"—*i.e.*, the number of revolutions—per Board of Trade unit. The pressure, and therefore the current, is maintained constant within one-half per cent., by the means described below.

Obviously there is a slight error in this method owing to the meters requiring time to get up speed, but this is compensated for in practice by their taking approximately the same time to slow down after the current is removed. When the current is so small that the time required for a run is inconveniently long, the meters are allowed to attain their full speed with that current and the centre hands are counted, the number of revolutions at the end of 1, 2, 3 . . . minutes being noted. With practice, it is easy to estimate to the tenth of a revolution, and these meters revolve with such remarkable regularity that repeated experiments have shown it to be quite safe to infer the constant from a two-minutes count. The rate per hour of the dials having been calculated, the constant is found as before. This meter, as has been shown, has so smooth a curve that it is sufficient to adjust it at two points, one being that of maximum current and the other one-tenth maximum.

The Ferranti-Wright meters are tested in exactly the same way as the last, except that the first method is always used, the centre needle never being counted. Three points are usually determined in the curve, one being the maximum current, one about one-seventh maximum, and one midway between the two.

The Frager meters also are strung in series, and the same precautions observed as regards exciting their shunts, but their different nature requires a different method of testing. There are two stages:—(i.) In the first the clock motor is timed and adjusted until it beats seconds within 2 or 3 per cent. (ii.) The meter as a whole is tested. The dials being set to zero, and the snails being in such a position that the levers have just left them (this is to allow them to become steady before engaging with the snails), the desired current is thrown on and the pressure, and therefore the current, kept constant within ½ per cent. until the snails have made six complete revolutions. When the lever of the slowest meter has left the snail, the current is taken off and the readings are noted. The known percentage errors of the clocks having been allowed for, the number of Board of Trade units that would have been registered by each in an hour is calculated, and this is compared with the actual amount that would have passed in an hour. The percentage error is then corrected by altering the ratio of the wheels between the snail spindle and the train as already described.

Passing on to the arrangements for performing the above tests, it may be well to remark that the space at the Author's disposal was extremely limited; two rooms, one above the other, each 28 feet long, 12 feet wide at one end tapering away to 3 feet at the other, having to suffice for testing-room, stores, Frager meter repairing shop and for containing the converters. The upper room was taken for testing, the lower for workshop, converter room and stores; a handlift in one corner formed a convenient means of communication. The testing-room is all that need be described; the narrow end is partitioned off, and a reflecting galvanometer and Wheatstone bridge placed in the chamber so formed; the galvanometer rests on a shelf supported on H iron cantilevers let into the wall, thus avoiding vibration. A space about 6 feet wide on the wall opposite the windows is faced with solid teak thoroughly coated with shellac, and to this are attached all switches; 5 feet 2 inches from the floor a shelf, supported like the one for the reflecting galvanometer, serves as a steady base for the ampere balances. Above this are fixed the primary fuses and switches from which vulcanized india-rubber covered cables, carried in iron pipes chased into the wall, lead to the converters in the room below.

A standard horizontal, tube-pattern, Cardew voltmeter, made by Messrs. Goolden and Co., is fixed below the switches, and shows the pressure on the shunt coils. Beneath the shelf are placed all the secondary switches. With a few trifling exceptions, the secondary connections for large currents are made of bare copper strip 1 inch by $\frac{1}{16}$ inch supported on teak cleats, coated with shellac, the number of strips being proportioned to the current to be conveyed. This is a very convenient and cheap method, and, when neatly done, looks well.

The mercury and Ferranti-Wright meters stand on narrow teak shelves one above the other, fixed on light T-iron cantilevers projecting from the wall.

It seemed desirable to be able to carry on tests of all three kinds of meter simultaneously, and so three separate testing circuits, each with its adjustable resistances and switches, were provided. A fourth circuit was added, for running meters from eighteen to twenty-four hours continuously on full load, to determine whether they would rise to an unsafe temperature.

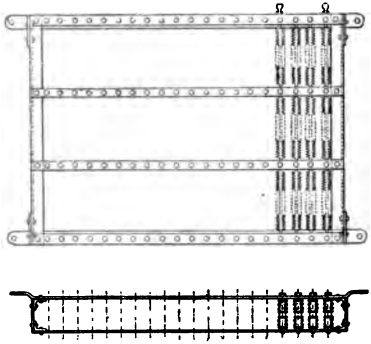
An obvious way of reducing the cost of testing is to feed the main coils with current at a low pressure, say 10 volts, and to excite the shunts only with 100 volts. After careful consideration, the Author decided not to adopt this plan, partly because he was not absolutely satisfied that it gave results identical with those obtained when both were excited from the same source, and partly because with many meters in series the pressure would have to be raised with large currents, and the additional complication entailed seemed hardly compensated for by the saving in expense. This objection clearly does not apply to the heating test, in which the shunts are not excited and no measurements are made; and accordingly a converter giving current at 10, 20, or 30 volts pressure at will in its secondary is employed, the lowest pressure that will give the desired current through the circuit being used, this pressure varying with the number of meters in series.

The mercury meter testing circuit is provided with resistances having a conductivity of 1·11 mho, divided into three sets, one of 1 mho, having ten steps of 0·1 mho each ; one of 0·1 mho, divided into ten steps of 0·01 mho each ; and one of 0·01 mho divided into five steps of 0·002 mho each. Each set has its members brought to a switch which, by the rotation of a handwheel, joins the desired number of coils in parallel one after the other. In this manner any current up to 111 amperes can be obtained by steps of 0·2 ampere.

It may be well to give a few details respecting these coils and switches.

Coils.—All the wires are of platinoid, and the diameter in no case exceeds 1½ millimeter, the object being to allow them to attain their final temperature rapidly. The coils that have to carry 10 amperes are of No. 17 B. W. G. bare platinoid wire, and are wound in two parallel oppositely directed spirals carried on circular

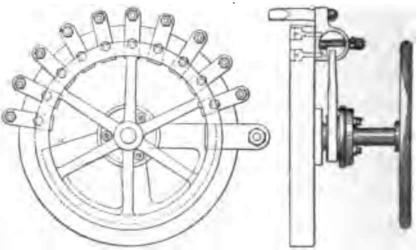
Fig. 13.



brown porcelain insulators, through which are passed bolts fixed to a light wrought-iron frame. The spirals are steadied by passing over two intermediate sets of insulators. Fig. 13, shows the arrangement. The other two sets of coil are wound on zinc cylinders about 3½ inches in diameter, split parallel to their axes to eliminate eddy currents, and each spiral is wound half in one direction and half in the other.

Switches.—Those for the 100-ampere and the 10-ampere coils have each eleven ring contacts, projecting inwards radially round a semi-circle. The first contact is of sufficient size to carry the whole current of the set of coils to which it belongs, while the other ten are in each case adapted to the current that flows through each member of the set. A brass sector, worked by a hand-wheel insulated from it, subtending the same angle at the centre of the switch as the eleven contacts, is so placed that when the hand-wheel is moved continuously in one direction, it is forced successively through all the ring contacts, thus connecting the ten one after the other with the first. The position of the hand-wheel thus determines the number of coils in parallel, and there is none of the annoyance experienced when a number of separate switches are used and an effort of memory has to be made to remember which switches allow the desired current to pass ; moreover, at full load there is no idle wire. The switch for the 1 ampere set is similar, but, of course, has only six contacts. The three sizes of switch are shown in Figs. 14, 15, and 16. It will be seen that the details vary slightly, but all are provided with brass eyes into which the leads are sweated.

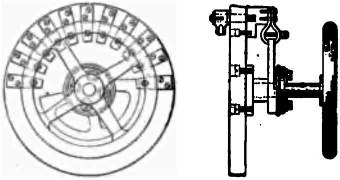
Fig. 14.



Ferranti-Wright meters are provided with an identical set of resistances and switches.

The Frager meter testing circuit has resistances having a conductivity of 22·2 mhos, the finest adjustment being 0·004 mho instead of 0·002. Only the third set is wound on zinc cylinders, the other two being of bare wire on wrought-iron frames, and the 2-mho set is on two separate frames, having 1 mho conductivity each.

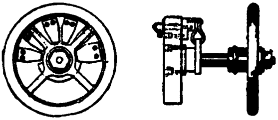
Fig. 15.



For the circuit for running the meters on full load, the pressure being only 10 volts, coils having a conductivity of 22·2 mhos are used, the adjustment being by steps of 0·04 mho. These coils are, of course, much shorter than those used with 100 volts pressure, but are mounted in the same general way.

With the exception of the last-named circuit, all are fed from an ordinary Ferranti 40-HP. converter, transforming from 2,400 volts to 100 volts, and therefore giving about 300 amperes in its secondary. This current is sufficient, since it is easy to so arrange the runs that it is not exceeded. There is a certain amount of drop of pressure at full load, even in this type of converter, which is exceptionally good in this respect, and the ordinary high-tension service mains being used, the pressure cannot always be relied upon to be exactly 100 volts. In order to obtain a constant pressure, the Author employs a subsidiary regulating converter, having its secondary in series with the main converter; it transforms down from 2,400 volts to 9½ volts,

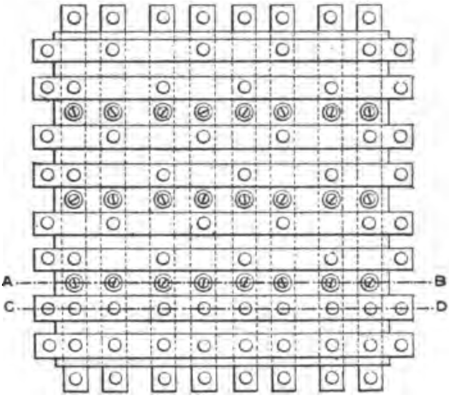
Fig. 16.

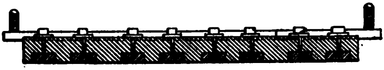


and will yield 300 amperes in its secondary. Connection can be made at ten points of its secondary, so as to obtain the current at a pressure of ½, 1½, 2½, to 9½ volts. By means of one two-way and ten-way switch, the pressure can be varied 9½ volts (see Fig. 18). In the primary is a reversing switch, so that this converter can either help or oppose the main. In this way a regulation of 9½ volts either way, or range of 19, is obtained. This, of course, is unnecessarily large, but it was designed for use when the Deptford works were still in a more or less experimental stage and the large margin was very useful.

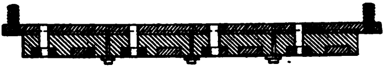
The current is measured by Lord Kelvin's standard balances, of which there are three, one reading nominally to 10 amperes but actually to 6 amperes (getting very hot even with this if the current is on for any length of time), one reading to 100 amperes and the third to 600 amperes. All these are required on each testing circuit though only one at a time ; in order, therefore, to render any one available for all circuits a switch is employed, consisting of two sets of bars running at right angles to one another, on opposite sides of a slab of slate. At alternate points of crossing, holes are drilled through bars and slate, being tapped in those at the back, and allowing brass bolts provided with insulating handles to pass through the front bars and the slate. These bolts have each a collar which takes a bearing on the front bar when the bolt is screwed into the back, thus connecting the bars. By means of two such bolts any two vertical bars, to which are connected the balances, can be joined to any two horizontal bars to which are brought the circuits. Two spare vertical bars or "bridges" with holes drilled at every point of intersection, take the place of the balance in the circuit without one (usually the heating circuit), and admit of changing from one balance to another without stopping the run. This switch is shown in Fig. 17.

The circuit is never broken with the plugs ; a single-break "pointsman" switch





SECTION ON A.B.



SECTION ON C.D.

PLUG.

Figs: 17.

is placed in each circuit, and admits of runs being started and stopped in any one circuit independently of the others.

The number of meters of any kind required to be tested at once is constantly varying, and if two fixed terminals only are provided between which to join them, a number of different lengths of cable for connecting them thereto are required; these are clumsy and unsightly, and the following has been found to be a convenient device. A series of brass bars, about 2 feet 6 inches long, having bolts and nuts projecting at intervals of 8 or 9 inches, are fixed on teak against the wall above the shelf on which the meters stand; bridging pieces serve to bridge across the gaps when required. Short pieces of very flexible cable, terminating in brass eyes, are used to join the ends of a set of meters to the nearest bolts of separate bars. On removing the bridging-piece connecting the bars, the meters are looped in. Another advantage of this is that a second batch of meters can be got ready at another part of the shelf while the first are running.

Fig. 18, shows diagrammatically the arrangement of the whole testing plant described above.

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